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SELF-CONTAINED ROBOTIC ARM MANIPULATOR

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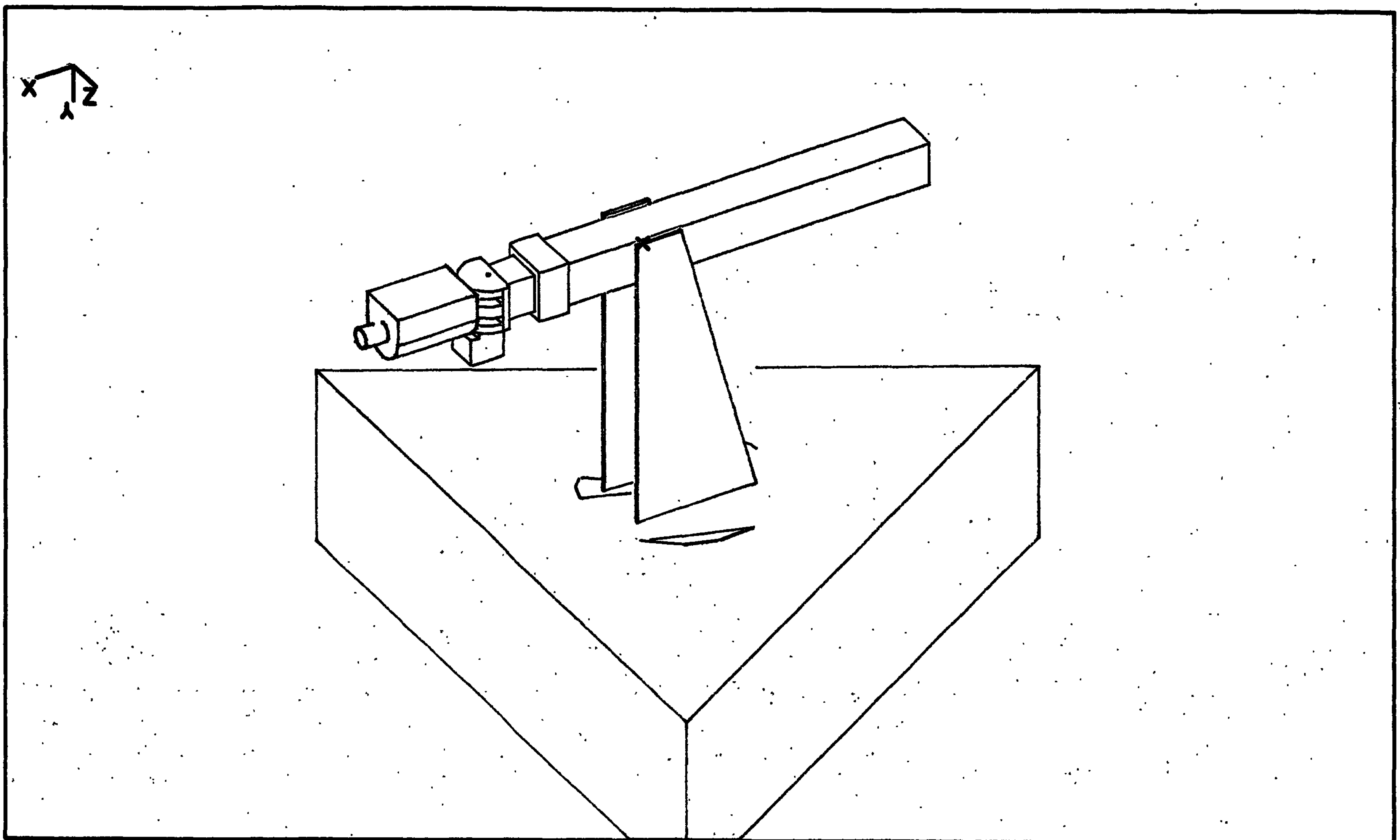
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INTRODUCTION

Problem Statement

The problem facing the space exploration program is that the lunar surface must be prepared for colonization. This preparation process must be coordinated and executed from earth. Since there is no human interaction, other than remote operations, there needs to be a way to set up and operate test equipment to check the environment. Once the construction equipment arrive on the lunar surface, this same implement must be able to repair any damaged equipment. A robotic arm type manipulator, when interfaced with SKITTER, is the solution to this problem. ~~Our~~ THE design , a self contained robotic arm manipulator (SCRAM), will be able to do repair operations, from changing a wheel on a lunar rover to salvaging useable parts from damaged equipment, as well as the placing of scientific test equipment. SCRAM will also be able to modify the construction equipment for various jobs. [illegible] MANIPULATOR [illegible] AND [illegible] GIVEN AND [illegible]

Background

To supplement it's space exploration program, NASA has proposed placing a manned space station on the moon. The first phase of this project, preparation of the lunar surface for colonization, will be performed by teleoperated or remote controlled robots. The pack horse of this phase will be the three legged walker called SKITTER. SKITTER will be used in this phase as a all purpose vehicle and manipulator. The need for SCRAM arose out of the necessity to test and analyze the site prior to construction, to place the appropriate test instruments and repair the construction implements that will already be on the moon.

PERFORMANCE OBJECTIVES

To fulfill the precise manipulatory tasks, a robotic arm will be used in conjunction with SKITTER. A heavy lifting device will be designed separately, in order that the arm need only a maximum lifting capacity of 50 pounds.force. The arm will work between two of SKITTER's two legs, giving it a working range parallel to SKITTER of 110 degrees and a working range normal to SKITTER of 90 degrees. In order to facilitate remote operation, a system of cameras will be integrated into the design of SCRAM. The power supply must be compatible with SKITTER, as well as being self contained. The end effector of the arm must be able to perform a large number of specific tasks while minimizing the number of and weight of the tools necessary to perform these tasks.

CONSTRAINTS

The design of SCRAM took into account many conditions and situations that would be encountered on the moon. We must design for the environmental conditions of the lunar surface. The first problem encountered is the huge temperature gradient, due to the lack of atmosphere. This will cause the working temperatures to range from -250 degrees Fahrenheit to 250 degrees Fahrenheit. This severely limits the types of materials and implements that can be used. The properties of the material cannot change due to long exposures to this gradient. the second aspect of the lunar environment that must be designed for is the extremely abrasive lunar dust. The lunar soil is comparable to a ground up grind stone. As a consequence, all moving parts must be as dirt proof as possible.

The second criteria that must be met is SCRAM must be as light weight as possible. The cost of getting an object into outer earth orbit is approximately $15,000 per pound, with an additional $7000 per pound to get the object to the lunar surface. Due to this, the weight of SCRAM must be minimized.

When these implements go to the lunar surface, there will not be any humans there. This, in itself, presents a problem. How will these implements be repaired if they malfunction? For this reason SCRAM must be as mechanically simple as possible, yet give the greatest amount of versatility. All functions of SCRAM will be either remotely or teleoperated with some operations automated. Not only must SCRAM be able to repair other components, but it must also be able to fix SKITTER and other SCRAMs.

The amount of power consumed by SCRAM must also be minimized. One of the parameters given for the entire space station is 75KW of power. SCRAM cannot take more than 2% of this for any one job. The consumption of energy will be controlled by a computer interface. This interface will be located on the earth for easy revision.

VIDEO

In order to give visual feedback to it's human operator, SCRAM will utilize two video receptors. The first will be located on the rotating drum of the base. This camera will be used as an aid in positioning SCRAM while providing a view of the working environment. The second camera will be located on the end effector and will provide visual feedback while changing tools and repair operations.

The heart of the visual system is a high resolution receptor chip manufactured by Kodak. This chip is 1 cm x 0.25 cm. It contains a square matrix of 1000 x 1000 pixels which are scanned thirty times a second. We have decided to use this high resolution chip and electronically magnify the images by using only a fraction of the pixals for the display. This will give us zoom capabilities without using a moving lens. The aperture to the potoreceptor will be very small giving us maximum depth of field. This combination allows us to get fairly good zoom capabilities without the problems of a mechanical zoom which would be very dust sensitive.

The photoreceptor produces an analog output which represents each pixel. The output for each of the one million pixals is given serially thirty times a second. Due to this high speed of analog to digital conversion a Flash A/D converter is needed. The digital signal of the picture can then be run through a data compression chip and sent to the remote control unit back on the earth.

This photoreceptor system could be developed into a way of automating SCRAM in the future. SCRAM could take that image and input it into a MPU, which contains the procedures to repair the object. Through this system the cameras could be eliminated from dangerous jobs.

The disadvantage in using these photoreceptors is that they are very sensitive to large temperature variations. In order for precise positioning of SCRAM via video images, the chips must be maintained within a specific temperature range. The use of thermopiles will be used to maintain this temperature range.

CONTROLS

SCRAM will be equipped with a microprocessor "brain" which will control many of the necessary operations of SCRAM. These operations include:

1. Energy management
2. Movement control
3. Video operations
4. End effector interface
5. SKITTER interface

Energy Management

In order to minimize power consumption, the micro processor unit (mpu) will insure that actions and motors are not all used simultaneously. This will prohibit the peak power demand from getting too large. In this way the average power consumption will be minimized. With the multiple degrees of freedom that SCRAM has, it is possible to position the end effector via many different paths. The energy management system will determine which configuration will minimize power usage by the motors and actuators.

Movement Control

The brushless D.C. motors that are used in SCRAM, are capable of position feedback. This information, coupled with feedback from the actuators and cameras, will be used by the MPU in the movement and configuration of SCRAM.

The movement control system will work in conjunction with the energy management system to determine the path and configuration that SCRAM will follow to minimize energy consumption and maximize system stability. This will be accomplished by controlling the motor RPM and actuator movement.

Video Operations

The MPU will convert the analog signal from the photoreceptors to a digital signal by using a Flash A/D converter. The video system will also provide the hardware and software for zooming the image created by the photoreceptors. It will determine the pixels of the total field are used to produce the entire output image. The video system will also provide the movement control system with visual data for position control.

End Effector Interface

This interface will provide a means of controlling any of the modular tools. For example, the hand will use the movement control system to control the movement of it's fingers. This will allow future tools access to a large MPU and allow information, such as necessary force, speed and position for various tasks, to be stored and used at a later date. This system will also control the rotary power head of the end effector.

SKITTER Interface

SCRAM must be able to interface with SKITTER in such a manner so as to use SKITTER's movement capabilities can be utilized. SKITTER must first place SCRAM in the work area in a position such that the object to be worked on is in SCRAM's work envelope. Then SKITTER may have to lean, raise or squat depending on the job SCRAM is to accomplish. This interface will also transfer position, force and visual information so that the movement control system can have adequate data.

MOTORS

In an environment of near vacuum motor operation is an essential consideration. In this type of an environment, the lunar surface, A.C. motors are naturally ruled out due to lack of efficient power supply. Also, conventional D.C. motors give rise to the complications of electrical arcing at the brushes making operation nearly impossible. Therefore, the alternative of brushless D.C. torque motors is the best remaining choice for our task. A brushless D.C. motor is simply an electronically commutated D.C. motor. The brushes and commutator are replaced by some type of position feedback and electronic switching.

In a conventional brush type motor the permanent magnet field and brushes are stationary so power can be applied to the brushes and the wound armature and commutator rotate. Since in a brushless motor power is fed directly to the wound armature the permanent magnet field is the rotating member.

In any D.C. motor the torque is produced by the interaction of the permanent magnet field with the current flowing through the windings. In a brush type motor the commutator switches the windings so that the proper relationship between magnet flux and armature current is maintained. In a brushless motor, however, we must sense the position of the magnetic field and turn on the appropriate windings to produce torque. This is normally done optically or with Hall devices but any absolute position sensor can be used.

Because the typical brushless motor rotates the inner member, the rotor inertia can be very low. This coupled with pulse torque capabilities results in acceleration rate that can exceed any other type of motor.
In addition to the elimination of electrical arcing brushless motors offer these advantages:

1. No brushes to wear out - higher reliability
2. Output not limited by brushes
3. No brush generated EMI - (electro magnetic interference)
4. extremely high acceleration - deceleration capability
5. better heat dissipation arrangement

The only significant problem areas are the requirement for more semiconductor devices than is necessary for the brush type D.C. motor and a slightly higher cost.

END EFFECTOR

Overview

Located on the end of SCRAM is a multi purpose end effector. The basic element of this effector is a brushless d.c. torque motor housed in a protective casing. Attaching to this motor is a planetary gear train, which uses a mixture of planetary and bevel gears to vary the output torque of the system. The end of this train contains the female connector for the interchangeable tools. In this female end there are electrical connections, similar in design to a coaxial cable. These contacts enable electro-mechanical operation in addition to strictly mechanical operation i.e. powering of the mechanical hand.

The male end of this connection is on the interchangeable tools. The hexagon shaft of the male end will be a perfect fit for the female end of the motor. This tight fit on the connection is to clear the female end of any debris and lunar soil that may have inadvertently entered the connection. The soil that gets into the connection will be pushed out the slots at the base of the female end.

The wide range of tools developed will be stored in spring loaded racks in the base of SCRAM. This will allow simple and efficient tool interchange.

The maneuvers of SCRAM will be remotely and teleoperated from earth. To enable the teleoperation of SCRAM, cameras will be strategically placed on SCRAM so as to allow the widest range of sight.

Design Criteria

In designing the end effector we took many aspects of the overall design into account. Namely the end effector must withstand a severe temperature gradient, be lightweight, dirt tolerant and consume very little power. Added to this is the criteria that the design must encompass many different types of jobs while keeping the number of tools to a minimum. This is accomplished through a multipurpose and interchangeable end effector. SCRAM's end effector has approximately twenty interchangeable tools, of which up to fifteen can be carried at one time. The majority of these tools will be job specific, with a few universal tools that accompany SCRAM irregardless of the job. The required tooling will be determined by the "brain" prior to deployment to the job site.

Specifications

TASKS

In designing tooling that would accompany SCRAM we anticipated a few of the tasks that SKITTER would be required to do. In the following listing of these jobs we indicate the steps necessary in completing the job.

Changing a wheel on a lunar rover

- Loosen and remove the lug nuts
- Remove damaged wheel and place on rack
- Grasp and place undamaged wheel and place on hub
- Retrieve lug nuts from rack and tighten

Replacing a Damaged Component

- Unhook latches on cover of module
- Reach inside, disconnect and retrieve damaged component, set aside
- Grasp new component and place in module, make mechanical and electrical connections
- Refasten cover on module

Placing Scientific Instruments

- Drill holes in surface for anchoring
- Grasp instrument and position for anchoring
- Tighten anchor bolts
- Activate instrument

TOOLING

The versatility required by SCRAM to perform all these different tasks creates a need for a complete system of interchangeable tools. This system must be complete, as stated, yet must be limited in the number of tools while maximizing the range of their function. In other words, each tool must be multipurpose rather than specialized. With these design criteria in mind, the tools included in this set are as follows:

1. Three Fingered Clamp/Hand

Description:
This hand, as all the tools, is connected by the insertion of the of the hexagonal shaft, but different in the use of electrical contacts in the base of the female end. This electrical connection controls the movement of the fingers of the hand. This manipulation is left to computer/microprocessor and/or visual control.

Function:
- General gripping and grasping
- Manipulation and positioning
- Light lifting
- Removal and storing of damaged and loosened parts and fasteners

2. Sockets and Extensions

Description:
The socket set used by SCRAM is that of a basic six point socket which includes the following:

- 3/8", 1/2", 9/16", 5/8", 3/4" and 1" inch sockets
- 1 - 6" extension
- 1 - 12" extension

Function:
- loosen nuts and bolts
- tighten nuts and bolts
- taking soil samples

3. Hooks

Description:
• 1 - 6" long, J shaped

Function:
• lightweight lifting and moving

Description:
• 1 - 6" long, L shaped

Function:
• pushing and pulling objects
• opening latches
• picking

Description:
• 1 - 6"long, J shaped. This hook is a permanent attachment to the arm.

Function:
• Heavy lifting
• Carrying the instruments to be positioned

4. Cutting Tool

Description:
• 1 - Electromechanical snips, 8" long

Function:
• Cutting away damaged parts
• Cutting wires

5. Spreader

Description:
- 1 - 6" long spreader mechanism (gear driven) with a maximum spread of 12".

Function:
- This implement will be used to gain access to salvageable parts of damaged equipment.

6. Riveter

Description:
- Mechanically operated riveter

Function:
- Refastening of covers that have been removed
- making mechanical and electrical connections

7. Drill Bits

Description:
- 3/8", 1/2", 9/16", 5/8", 3/4" and 1" drill bits

Function:
- Drilling anchor holes for instruments

MOTOR

The output torque range required for our system is 1 - 20 ft-lb. Since we knew the required out put torque, the rpm of the main motor could be determined. This equation was then juggled until we arrived at a acceptable rpm value for both of the torque motors. With the gearing we designed, the main motor is required to have a minimum output of 400 rpm. The motor running the ring gear must give a range from 0 to 1600 rpm. Once these values were established, we then examined the motor specifications to determine which motors would meet the rpm, weight and power consumption requirements. The motor that we chose for the main torque motor is the Inland Motor Company model #BM-3201. For the ring gear motor, the Inland motor company model #BM-0702 was chosen. (See appendix A - Motor Specifications)

GEAR TRAIN

During repair operations the rotary power head will be required to provide a variable torque range. We determined the desired range of 1 - 20 ft-lb. The lower torque limit will be used during the insertion of nuts and bolts so as to prevent cross threading. The upper limit will give enough torque to break loose fasteners, such as nuts and bolts, that have become stuck or crossthreaded. Our main torque motor provides 3.4 ft-lb of torque at 438 rpm, Inland Motor Company model #BM-3201. A planetary gear train, utilizing an Inland Motor Company model #BM-0702, gives the ability to vary the torque. In order to obtain the maximum torque, 20 ft-lb at 210 rpm, the ring gear is locked using an actuator activated brake. In order to obtain the lower torque range, the ring gear is unlocked and the smaller torque motor is varied from 0 to 1600 rpm. in this mode of operation the output torque is 1 ft-lb of torque at 1700 rpm.

The sun gear is attached to the output shaft of the main torque motor (model #BM-3201). The output torque is generated by a 2.08" planet gear that interfaces with the sun and ring gear. The ring gear is 5.25" inside diameter and surrounds the BM-3201. The ring gear interfaces with a 6" bevel gear at a 90 degree angle. The bevel gear transfers power from the smaller BM-0702 torque motor to the ring gear when the power head is performing reduced torque operations. (See Appendix B - Gear Train calculations and illustrations)

TOOL RACK

Positioned in the base of SCRAM is a storage area for it's interchangeable tools. Each separate tool is held in it's own holder when not in use. These holders consist of a spring loaded trapping mechanism to hold the tool while engaging or disengaging the tool. The rack consists of fifteen separate holders 3" across the bottom, 4" high and 6" deep.

SCRAM will engage the tool by placing the male end of the tool into the female end of the end effector and pushing in an upward motion. This secures the tool, making the electrical connection, if necessary. The tool is disengaged from it's holder by a motion parallel to the plane of SKITTER's body. This motion is done with enough force to pull the grips apart. To disengage the tool, the opposite sequence of steps is used. First the tool is placed in it's holder by applying enough force to pry the grips apart then a downward motion disengages it.

Also included in this rack is an area to store the nuts and bolts that have been removed from an object. The area for the nuts consists of a series of threaded dowel rods 6" long corresponding to the threads that would be standard on a lunar implement. A series of threaded holes will be used for the removed bolts.

OVERALL SPECIFICATIONS

Overall Length	13.625 in.
Width	7.25"
Height	7.25"

Weight

Gears

Planet Gear.. 0.223 lb
Ring Gear ....3.158 lb
Sun Gear/Shaft ....0.375 lb
Bevel Gear ....1.539 lb
Output Shafts... 5.345 lb

Housing

33.4 sq.in of 3/8" Aluminum..........11.726 lb

Motors

Inland Motor Co.
Model #BM-3201...................................4.0 lb
Inland Motor Co
Model #BM-0702...................................0.5 lb

Motor Supports

4 - 6" long 1"x1"x1/8"
Equal Angle ....2.12 lb
Motor support plate................................0.24 lb

Total 25.94 lb

Power Consumption

Inland Motor Co
Model #BM-3201......................................159 watts (peak)
Inland Motor Co.
Model #BM-0702..112 watts (peak)

ARM

Overview

The arm assembly on SCRAM must be capable of performing several functions. It must be strong enough to support a wrist assembly consisting of two motors with their associated gear trains and covers, the end-effector with its motors and gear train, and a 50 lb. force in any direction at the tip of the end-effector. Furthermore, the arm must possess enough flexibility to manuever the end-effector into a variety of different positions without sacrificing strength. Weight is also an important consideration; the weight of the arm should be as low as possible. In order to accomplish these objectives, we designed an arm consisting of three distinct parts: a hollow sleeve, a translating hollow arm inside of the sleeve, and a wrist at the end of the translating arm.

The hollow sleeve, which is attatched to permanent plates on the base, is restricted to a pivoting motion between these two vertical plates. Inside the open end of the sleeve, there are four rollers (one on each side), which aid in the translation of the inner arm. On the enclosed side of the sleeve, the motor and the power screw are attached, which apply the force necesary to slide the inner arm in the desired direction. On the end of the sleeve, a plastic accordion-type boot is attatched, with its other end being attatched to the translating arm. This boot will prevent dirt from entering the sleeve/translating arm assembly and causing damage to the rollers, power screw, and gear train. This boot should also be treated to prevent outgassing of the plastic material.

The translating hollow arm is slid along the inside of the sleeve by the power screw/motor combination, and is capable of extending or retracting 2 feet. At the beginning of the translating arm, deep inside of the sleeve, there are four more rollers (again, one on each side) built into the arm to help ease the translation motion. The power screw rotates inside of the beginning of the translating arm, allowing it to move in and out.

The wrist is located at the end of the hollow end of the translating arm. It consists of two motors and their gear trains, the wrist itself, and the pivoting and rotating supports which pivot and rotate the end-effector through its range of motion. One motor and gear train is located inside the end of the translating arm, and it rotates the wrist (and end-effector) on a shaft about the longitudinal axis through the translating arm. The second motor pivots the end-effector about an axis perpendicular to the longitudinal axis, thus giving the wrist two degrees of freedom. This second motor and gear train is located on one side of the wrist, applying its work through two pivot supports attatched to the end-effector. This provides a great deal of flexibility in positioning the end-effector, while remaining relatively lightweight and mechanically simple.

Design Criteria

As with all lunar equipment, weight had to be minimized. From a cost standpoint, transportation to the moon is estimated to be $22,000 per pound; therefore, we designed SCRAM to weigh under 1,000 lbs., and still remain a functional tool. From an energy standpoint, we also wanted to keep the power consumption to a bare minimum, because the entire lunar base will only have 100 KW; our goal was to keep our arm power consumption under 5 KW. Both of these design criteria worked well together, since the lighter we made our arm, the less power we needed to run the smaller motors.

Another criteria that has to be considered when designing for the moon, pertains to dealing with the lunar environment. This environment subjects the design to very large temperature gradients, which can have adverse effects on the materials used in the design. Also, the lunar dust is a highly abrasive substance which can ruin many of our more vulnerable parts such as; rollers, ballbearings, and gear trains.

Specifications

SLEEVE

The sleeve contains a motor and extending actuator. The motor drives the actuator, which turns a power screw, which extends or retracts the translating arm.

Extending Actuator

* Duff- Norton mechanical actuator
* Model #4555, 1/4 ton capacity with anti-backlash feature
* Upright rotating ball screw
  - 4 in. closed length
* Extends 2 ft., with extra 2 in. for secure hold
* .375 in. diameter bore
* Matierial : steel

Rollers (4)

* .5 in. diameter
* 3.8 in. long
* Attatched to open end of sleeve (1 per side)
* Material: steel

Sleeve

* .5 in. thick square base
* .35 in. thick sides
* Hollow square, 5.9 in. X 5.9 in. (outside length)
* 48.5 in. long sides
* Material: aluminum

TRANSLATING ARM

Translating Arm

* 52.5 in. overall length
* .375 in. diameter bore in solid part of arm for extending actuator
* Material: aluminum

Rollers (4)

* .5 in. diameter
* 3.00 in. long
* Attatched to beginning of solid part of translating arm (1 per side)
* Material: steel

WRIST

Motor #1 rotating shaft

* .375 in. diameter
* 9 in. long

Motor #2 rotating shaft

* .5 in. diameter
* 2.5 in. long

Pivoting supports for Motor #1 rotating shaft

* 3.6 in. long
* 1.0 in. X 1.0 in. solid square

MOTORS

Motor #1: attatched to side of wrist

* Aeroflex. Motor Co. Model #V34-26
* Continuous torque: 86 oz-in. @ 786 rpm
* Peak torque: 180 oz-in. maximum

Motor #2: attatched inside end of translating arm

* Aeroflex Motor Co. Model #TQ34W-12
* Continuous torque: 60 oz-in. @ 1870.63 rpm
* Peak torque: 80 oz-in. maximum

Motor #3: attatched inside of sleeve;
powers translating actuator

* Will be designed to our specifications by Inland Motor Co.
* Continuous torque: 208 oz-in. @ 1200 rpm
* Peak torque: 400 oz-in. maximum

GEAR TRAINS

In order to reduce the total weight required for each of the motors in the arm design, gear trains of high order reduction are utilized, so that much smaller, lighter motors could be used. Typically, the gear reduction was between 200:1 and 500:1, depending on the torque and speed required. Every individual gear in each of these gear trains is made of solid steel, in order to obtain the high strength needed for these large gear reductions.

Typically, these gear trains are exposed to the possibility of dirt contamination, so they must be covered. To minimize their exposure to the lunar dust, these covers must be placed in such a way as to prevent the dust from entering the gear train, yet not hinder the movement of the different gears. Furthermore, the motor shaft and the motor should not be covered, so that the motor may radiate its heat to the surroundings.

DIRT CONTAMINATION

When designing the robotic arm, we had to design all parts to withstand the tough lunar dirt. This dirt has a strong tendency to cling to wherever it lands (due to electromagnetic forces). The dirt is also very abrasive, and could create extensive damage if it got in the gear trains.

Therefore, the gear trains and the rollers inside of the telescoping arm must be protected from the lunar dust. The gear trains are to be enclosed by sheets of aluminum on all sides. This arrangement should keep the dust from entering the gear train.

The roller bearings inside the arm will be protected by a flexible accordion-type plastic membrane, which will attach to the sleeve at one end and to the translating arm at the other end. This plastic will be of the treated type to resist the tendency for "outgassing" of plastics in the lunar environment. Since the attachments at both ends of the plastic are permanent, there should be no possibility of lunar dust entering the rolling mechanisms or ball bearings in the sleeve. Each roller will be sealed with a labrynth seal to help avoid dirt contamination, and allow smooth easy rolling action for the translating arm.

RANGE OF MOTION

The SCRAM was designed for the bottom of SKITTER, which has a very good range of motion itself. Therefore SCRAM's purpose was more focused on stability within its range of motion.

The SCRAM unit will operate only between two of SKITTER's legs;therefore, its range of motion at the rotating drum in the base is 120 degrees. The pivot point for the telescoping arm is located three feet below the rotating drum. The range of motion for this pivot is 150 degrees, from vertically down towards the ground to 30 degrees from vertically up.

The telescoping arm can remain retracted (as seen in drawing) or it can extend the inner arm 2 feet beyond its 4 inch retracted length. The telescoping inner segment can be stopped at any point during its translation and will be held steadily by the self locking action of the worm gear.

The wrist has 2 degrees of freedom. One rotates at the point where the wrist meets the end of the telescoping arm; this joint has a 360 degree range of motion. The other degree of freedom is located on the wrist and turns the end effector through a 180 degree range of motion from 90 degrees to either side of the center line through the sliding arm.

ENGINEERING ANALYSIS

In the appendix, there are many calculation to determine the specifications presented throughout the text. Every motor specification is based on a torque requirement that each particular motor must exceed. The torque is determined by the product of the force times the distance between the line of action of the motor and the line of action of the force. Symbolically,

$$\text{Torque (T)} = \text{Force (F)} * \text{Distance (d)}$$

Summing up these torques yields the static torque requirement. In order to develop acceleration, the motor must exceed this torque specification. In our design, we have attempted to specify motors which are rated 10-15% higher torque than the static torque requirements. Often, however, the torque needed would be quite considerable;therefore, a gear train was introduced. The gear train had the effect, using the mechanical advantage derived through gearing, of allowing a much smaller motor to generate the given torque requirements. The trade-off in this advantage was the loss of speed in the output, however, having a slower output allows for more precisely controlled movements; one of the major assets.

Further calculations to determine the weights of objects relied on simple geometry, and the density of the two metals: .100 lb./in.^^3 for aluminum, and, .282 lb./in.^^3 for steel. The volume of an object was multiplied by its density to yield its mass. Deflections were calculated based on the dimensions of the given situation, using mechanics of deformable bodies. Other calculations were also made concerning areas like torsion and stress, and these can all be found in the back of the report in the appendices.

OVERALL SPECIFICATIONS

Weight

Arm

Sleeve..47.513 lbs.
Translating Arm..........................39.927 lbs.
Actuator...04.330 lbs.
Rollers & Ball Bearings............03.250 lbs.
Shim (for gears)........................00.908 lbs.
TOTAL.........95.928 lbs.

Wrist

Gear Train #1................................1.797 lbs.
Gear Train #2................................2.915 lbs.
Shaft #1..0.819 lbs.
Shaft #2..0.130 lbs.
Wrist..20.297 lbs.
TOTAL...25.958 lbs.

Motors

Motor #1..1.875 lbs.
Motor #2..1.310 lbs.
Motor #3..0.750 lbs.
TOTAL.....3.935 1

TOTAL WEIGHT = 125.821 lbs. (plus end-effector)

Power Consumption

Motor #1.......................................230 watts peak
Motor #2.......................................180 watts peak
Motor #3.......................................400 watts peak
TOTAL.....810 watts peak

TOTAL WATTS = 1081 watts peak (including end-effector)

BASE

Overview

The base assembly on SCRAM must be capable of performing several functions. The base must have the proper mechanism to attatch to SKITTER. The base must provide an area suitable for microprocessors, power supplies, tools, and telerobotic communication equipment. Furthermore, the base should be able to support and rotate the arm section. The base must be lightweight, as well. In order to accomplish these objectives, we designed a base consisting of three distinct parts: a drum, a frame, and two plates.

The base has three, 2 in. steel balls located at the corners of the frame, which is a seven foot equilateral triangle. These balls serve as the interface between SCRAM and SKITTER. The frame provides the area in which to locate the microprocessors, power supplies, tools, and telerobotic communications equipment. The frame also supports the drum. The drum is the rotating member of the base, and the two plates attatch to the bottom of the drum. The other end of the two plates is attatched to the sleeve, and allows the sleeve to pivot between the plates. Thus, the sleeve can pivot up and down between the plates, and rotation of the drum will cause rotation of the arm as well.

Design Criteria

In addition to the criteria previously discussed (protection from the abrasive lunar soil and the large thermal gradients, and the necessity of designing for lightweight), several other factors are very important in base design. The largest stresses in the arm will be present in the base; consequently, the base must be designed to withstand high stress levels.

The interface between SCRAM and SKITTER is also a crucial factor. The base must fit onto SKITTER and be strong enough to counteract the strong moment force generated when a load is being applied and the arm is fully extended.

Specifications

DRUM

In order to obtain the desired rotation at the base, a drum was designed that would rotate between two ball-bearing tracks (ring guides). The ring guides will be directly attatched to the frame in order to resist any bending moments created by the arm. The ball-bearings in the ring guide are .3 in. diameter steel ball bearings. The bearings lie in two - 27 in. tracks, and number 280 ball bearings per track. These tracks are attatched to the frame on the top and bottom of the drum to help distribute loads.

The drum has teeth around the top circumference, and a small D.C. brushless torque motor will drive a worm designed to mesh with those teeth. The bottom of the drum is flush with the bottom plate of the frame. Two - .4 in. thick plates attatch to the bottom of the drum to support the rest of the arm.

The dimensions and weights are calculated in the index.

Drum

* 30 in. diameter at top of drum
* 24 in. diameter at bottom of drum
* 5.6125 in. total height of drum
* 0.4 in. thick throughout drum
* worm gear teeth around top of drum

Ring Guides
* 2 - 27 in. circular ball-bearing tracks
* Each guide contains 280 ball-bearings.

FRAME

The frame is composed of two identical equilateral triangles, each seven ft. on a side. One triangle is two feet above the other, and is supported at all three corners by vertical supports and crossbraced by diagonal supports. Inscribed in the bottom triangle is a smaller equilateral triangle, which serves as the support for the rotating drum. A skin of 1/16 in. aluminum covers all sides of the frame, and angle irons in the corners attatch the skin to the members.

The members are 3 x 2 3/8 in. aluminum I-beams. The horizontal, vertical, and diagonal beams are placed such that each beam has a flange facing in a different direction (towards the X,Y, or Z axis). By having each beam face in a different direction, better overall strength is achieved.

At the top of each corner of the frame is an interface that attatches to SKITTER. Each interface consists of a two in. diameter steel ball mounted on a one in. diameter, one in. long steel shaft, and secured to the base with a one in. diameter titanium bolt.

Frame

* 3 - 7.2801 ft. diagonal crossbraces
* 3 - 2.00 ft. vertical supports
* 6 - 7.00 ft. horizontal members (3 for top, 3 for bottom)
* All members - 3 x 2 3/8 aluminum I-beams

Angle Irons

* 12 - 2 1/2 x 2 aluminum angle irons
* Angle irons are 3/16 in. thick
* Aid in attatching aluminum skin to frame

PLATES

The two plates are secured to the bottom of the drum at one end, and to the sleeve of the arm at the other end. A motor and gear train on each side of the plate, where it joins to the sleeve, serve to pivot the sleeve up and down between the two plates.

Plates

* 0.4 in thick
* 16 in. across at the end that attatches to the drum
* 6 in. across at the end that connects with the sleeve
* 24 in. high (from drum to sleeve)

MOTORS

Motor 4: (2 of them), one per plate : rotate sleeve

* Aeroflex V40-8
* Continuous torque - 190 oz.-in. @ 572 rpm cont.
* Peak torque - 315 oz.-in. @1186 rpm peak.

Motor 5: drives worm to rotate drum

* Aeroflex V40-8
* Continuous torque - 190 oz.-in. @ 572 rpm cont.
* Peak torque - 315 oz.-in. @ 1186 rpm peak

GEAR TRAINS

Two different gear trains are utilized in the base design. The most simple one is the gear train for the motor that rotates the drum. The top of the drum has a 30 in. diameter. With that large of a circumference (94.278 in.), it was possible to put a 600 tooth worm gear around the top edge of the drum, and drive it with a double-enveloping worm. Such an arrangement yielded a 300:1 gear ratio.

The two gear trains on the plates pivot the sleeve, and they are identical. The motor drives a 12 tooth gear, which drives a 48 tooth gear, which drives a single enveloping worm, to turn a 50 tooth worm gear at the sleeve end. This gear train produces a 200:1 gear ratio.

SPECIFICATIONS

Weight

Base

Gear Train #4...(2 x)....................	9.905 lbs.
Gear Train #5................................	1.125 lbs.
Shaft #4..	0.819 lbs.
Shaft #5..	0.130 lbs.
TOTAL...	25.958 lbs.

Motors

Motor #4.........(2 x)......................	6.875 lbs.
Motor #5..	3.4375 lbs.
TOTAL...	10.3125 lbs.

Drum

Drum	71.7257 lbs.
Ring Guide ....(2 x).............	66.5364 lbs.
Ball Bearings ......(all)................	2.2325 lbs.
TOTAL....	140.4946 lbs.

Plates

Plates ....(2 x)..............	34.320 lbs.
Spacers and Pins .... (to attatch plates to sleeve)	1.8421 lbs.
Hook .... (on bottom of sleeve)	1.13 lbs.
TOTAL....	37.2921 lbs.

Frame

I-beams............(all)...............187.285 lbs.
Angle Irons......(all).............. 21.229 lbs.
Skin.....(1/16 in. on frame) 56.70 lbs.
TOTAL...265.214 lbs.

TOTAL BASE WEIGHT = 443.000 lbs.

Power Consumption

Motor #4..........(2 x)...............550 watts peak
Motor #5..................................275 watts peak
TOTAL....825 watts peak

TOTAL BASE WATTS..825 watts peak

TOTAL ARM and END-EFFECTOR WATTS ....1081 watts peak

TOTAL WATTS FOR SCRAM ....2.006 KW.........2006 watts peak

TOTAL BASE WEIGHT..443.000 lbs.

TOTAL ARM WEIGHT...128.821 lbs.

TOTAL END-EFFECTOR WEIGHT....................................25.940 lbs.

TOTAL SCRAM WEIGHT..597.761 lbs.

These figures leave 402.239 lbs. for the power supply, microprocessors, end-effector tools, and telerobotic communications equipment.

RECOMMENDATIONS

The time constraints of a single quarter introduce incompleteness on the design of such an instrument as SCRAM. Our report dealt with only the first stages of design. In this stage we attempt to gather as much data as possible, come up with supporting numbers and perform appropriate calculations to predict the feasibility of the project.

While making these calculations and proceeding toward our final design, we came up with several designs that we found were not feasible. The original design for SCRAM was eliminated because it was determined that the arm would be too heavy to fit in our original constraints. In another design, we had a seven degree of freedom arm. This design was over ruled when it was decided that this was over design. A third design called for a very intricate arm with many degrees of freedom and large scope of work but, this arm was found to be much too fragile for our application.

Without the restrictions of time, We would have better considered or performed a more in depth analysis of the project. Some of the areas that need to be covered in greater detail are larger optimization of weight and better power usage. In our design we made calculations for solid gears and reduced these by certain percentages. The analysis of a spoked gear train would a more accurate representation of weight. A weight reduction in the gear train would reduce the torque requirements and thus allow the use of lighter weight torque motors. The gear trains, although well designed at this point in function, could be altered slightly to give better efficiency. By general size and weight optimization the motors will run more freely and watt usage will be at a minimum.

Power usage can also be minimized by a better structural analysis, from a materials stand point. Materials such as composites or epoxies would take the place of the materials that we used in our design. This would reduce the weight, as well as the power consumption, while at the same time strengthening our system.

Consideration for the future development of the end effector could be much the same as for the arm. The motor and gearing compose the majority of the weight and account for it's total power consumption. If a system of interchangeable motors were to be designed to meet the requirements, it would eliminate the need for both a motor and a gear train. this would decrease the weight and increase the simplicity of the design. These interchangeable parts allow the luxury of having spare motors, should one malfunction. Having the motors fit the job, would allow the motor to run at optimum speed and torque, thus eliminating the overwork or underworking of these motors. The end result of this is an more efficient usage of power.

APPENDICES

APPENDIX A

SCRAM

Progress Report - Week 1 - Group E

Self Contained Robotic Arm Manipulator

Raymond (Buzz) Kleinert
Jeff Earnest
Doug Dean
Dexter Edge
Greg Louden
Paul Hill

We spent this past week organizing our group. We had planned to meet with Mr. Brazell on Thursday to get the specifics of our project, but our meeting was cancelled due to inclement weather.

1. Earnest, Jeff - Jeff began to acquaint himself with GEODRAW and the APOLLO computer system.

2. Kleinert, Buzz - Buzz, serving as the group leader, organized the group over the week-end. He also attempted to contact Mr. Brazell on Monday and Tuesday for a group meeting on Tuesday, but was unsuccesful.

3. Edge, Dexter , Louden, Greg , and Hill, Paul - Dexter, Greg, and Paul began library research on Monday and Tuesday, but couldn't find the mentioned papers on lunar bases in the library.

4. Dean, Doug - Doug began to familiariize himself with the VM mainframe system, script editor on the IBM system and the microfiche papers in the design lab.

S C R A M

Progress Report - Week 2 - Group E

Self Contained Robotic Arm Manipulator

Raymond (Buzz) Kleinert
Jeff Earnest
Doug Dean
Dexter Edge
Greg Louden
Paul Hill

This week, our group met on Thursday afternoon and planned to spend several hours individually over the week-end preparing ideas for our group brainstorming meeting on Monday evening. The objective of Monday's meeting was to prepare our problem statement and weekly progress report, in order to put the information on the computer on Tuesday. Our group also planned to attend an instructional class on GEODRAW to better understand that system.

1. Earnest, Jeff & Dean, Doug - In addition to doing group participatory work, Jeff and Doug typed our progress report and problem statement on the computer.

2. Kleinert, Buzz - Buzz, in addition to organizing group participatory work, organized a meeting with Eddie Bowden so that our group could get an introduction and an account for the APOLLO computer system. He also organized a phone meeting for Thursday with Mr. Brazell, if problems arise.

3. Edge, Dexter & Hill, Paul - In addition to group participatory work, Paul and Dexter began contacting leading professors on campus for more detailed help in robotic control.

4. Louden, Greg - In addition to his group participatory work, Greg read material on sensors and manipulators in books available in the design lab (French rm. 232). Greg also did some research on the microfiche in the design lab.

SCRAM

Progress Report - Week 3 - Group E

Self Contained Robotic Arm Manipulator

Raymond (Buzz) Kleinert
Jeff Earnest
Doug Dean

Dexter Edge
Greg Louden
Paul Hill

This week, our group met on Thursday afternoon and divided into two seperate sub-groups: arm assembly and end-effector. Each sub-group decided to brainstorm individually over the weekend and to present their ideas at Tuesday's sub-group meetings. Information was gathered via consultations with Professors Dickerson and Lipkin, and also through more intensive library research. The group received general instruction on and accounts for the APOLLO computer system.

Arm Sub-group

Kleinert, Buzz
Edge, Dexter
Dean, Doug

End-effector sub-group

Hill, Paul
Earnest, Jeff
Louden, Greg

1. Arm sub-group - Met with Dr. Lipkin to discuss possible arm configurations and referenced textbooks on robotics to aid in our arm configuration analysis. In addition to both group and sub-group work, we wrote and typed the progress report for this week.

2. End Effector sub-group - In sub-group meetings this week, members defined end-effector objectives and began preliminary design work on the end-effector. A decision was made to have an end coupler with modular tools adapted to fit on the end. Each tool would therefore be specialized, but all tools would have the same mating end to attach to the arm.

SCRAM

Progress Report - Week 4 - Group E

Self Contained Robotic Arm Manipulator

Arm Sub-group
Raymond (Buzz) Kleinert
Dexter Edge
Doug Dean

End-effector Sub-group
Jeff Earnest
Greg Louden
Paul Hill

This week, each sub-group began to expand on the ideas that were developed at the previous meetings. Preliminary sketches were developed for several versions of both the arm and end-effector, and are to be prepared on the CAD system for presentation at this week's group meeting on Thursday with Dr. Brazell. We also discussed the format for the group's oral progress report presentation (in class, at midterm), and began to prepare for this presentation. Further library research was accomplished this week, utilizing searches on the BRS terminal system at the Tech library. These searches located many useful books on robotics, control theory, coupler design, end-effector configurations, and robotic vision systems.

1. Edge, Dexter - In addition to good participatory work in both group and sub-group meetings, Dexter began reviewing some of the books we checked out from the Tech library.

2. Dean, Doug - Doug reviewed several of the books located in the library search, wrote and typed this week's progress report, in addition to fine group/sub-group participatory work.

3. Kleinert, Buzz - Buzz did the preliminary design sketching, as well as the CAD drawings of the possible designs, along with good group and sub-group participation and book review of library matierials.

4. Earnest, Jeff - Jeff worked with Paul on developing the particular end-effectors to attatch to the arm, and reviewed books found in the BRS library search.

5. Hill, Paul - In addition to the work with Jeff on the end-effector design, Paul reviewed library matierial he found using the library search.

6. Louden, Greg - Greg aided Paul and Jeff in end-effector design, as well as making preliminary sketches and CAD drawings and reviewing library matierials.

S C R A M

Progress Report - Week 5 - Group E

Self Contained Robotic Arm Manipulator

Arm Sub-group
Raymond (Buzz) Kleinert
Dexter Edge
Doug Dean

End-effector Sub-group
Jeff Earnest
Greg Louden
Paul Hill

This week, the two sub-groups spent time together planning the oral progress report to be presented to the class this week. We decided to utilize both overhead projections of our current status and design , as well as using a computer simulation of our robotic arm (which will display the motions possible by our arm). In our full group meetings this week, we continued library research and planned the mid-term presentation. Particular problems to be addressed in the coming week include locating electric motors which will operate in the necessary temperature ranges, the vision system, dust removal from optical surfaces, and motor specification.

1. Edge, Dexter - In addition to good participatory work in both group and sub-group meetings, Dexter collaborated with Doug and Paul on the speech for the oral presentation, and did the graphics on the MacIntosh for the mid-term presentation.

2. Dean, Doug - Doug worked with Paul and Dexter on preparing the problem statement for the mid-term presentation, wrote and typed this week's progress report, in addition to good group/sub-group participatory work.

3. Kleinert, Buzz - Buzz continued the design sketching on CAD, as well as working with Greg on the computer graphics of SCRAM for the mid-term presentation. Buzz continued good group and sub-group participation and book review of library matierials.

4. Earnest, Jeff - Jeff worked on the MacIntosh, preparing text and graphics to be used in the mid-term presentation, and began to search the VMSL (vendor catalogs) in the Tech library.

5. Hill, Paul - In addition to the work with Doug and Dexter on the problem statement for the oral presentation, Paul continued to search the library for additional project information, using the VMSL (vendor catalogs).

6. Louden, Greg - Greg worked with Buzz to prepare the graphics of SCRAM for the presentation, in addition to good group/sub-group participation and continuing CAD drawing of the arm.

SCRAM

Progress Report - Week 6 - Group E

Self Contained Robotic Arm Manipulator

Arm Sub-group

Raymond (Buzz) Kleinert
Dexter Edge
Doug Dean

End-effector Sub-group

Jeff Earnest
Greg Louden
Paul Hill

This week, the two sub-groups spent time attempting to define exact specifications for various parts of the arm. The arm group is interested in utilizing a computer program Brice and Gary mentioned that they found useful in designing SKITTER. This program will analyze the stresses in a member (such as an arm segment) in order to facilitate minimizing the stresses.

Other progress made this week includes utilizing an LPI search, organizing the commercial library search with the librarian, and experimenting with a matierials selection program on loan from Dr. Colton. Further progress was made on the CAD system this week by both subgroups, as well as continued research in library matierials and the VSMF (vendor catalogs).

1. Edge, Dexter - In addition to good participatory work in both group and sub-group meetings, Dexter conducted an LPI search and continued to make use of library references.

2. Dean, Doug - Doug read several library texts on robotic technology and joints and couplers, wrote and typed this week's progress report, in addition to good group/sub-group participatory work.

3. Kleinert, Buzz - Buzz continued the design sketching on CAD, as well as working with Greg on preparing the information for the commercial library search. Buzz continued good group and sub-group participation and book review of library matierials.

4. Earnest, Jeff - Jeff continued to search the VSMF (vendor catalogs) in the Tech library, in addition to good group/sub-group participatory work.

5. Hill, Paul - Paul spoke with Mr. Dave Easters of Battelle Columbus Labs about tools he designed for sattelite repair. Paul continued to search the library for additional project information, using the VSMF (vendor catalogs).

6. Louden, Greg - Greg worked with Buzz to prepare the commercial library search, in addition to good group/sub-group participation and continued CAD drawing of the arm.

S C R A M

Progress Report - Week 7 - Group E

Self Contained Robotic Arm Manipulator

This week, the two sub-groups began to finalize the exact specifications for various parts of the arm. The arm group has made some progress in using GEOMOD for analyzing the arm, although attempts to use SUPERTAB to perform engineering analysis have been unsuccesful. Further work was done in verifying the results of GEOMOD by checking them with the equations for deflection and stress.

The end-effector group made continued progress in determining the reqired bolt torques and shear specs, as well as reviewing the matierial Paul received from Dave Easters of Battelle Colubus Labs. Mr. Easters has designed a set of tools for satellite repair, which may be adaptable for use on the end-effector. Other progress included finishing the commercial library search and vendor catalog research.

1. Dean, Doug - Doug began to derive equations for deflection and shear stress, in order to check the results of GEOMOD, as well as attempting to convert GEOMOD files for use in SUPERTAB, and writing and typing this week's progress report.

2. Earnest, Jeff - Jeff coordinated with a Georgia Tech librarian to determine bolt torque and shear specifications for the end-effector.

3. Edge, Dexter - Dexter put several models of the arm on GEOMOD for conversion to SUPERTAB for stress analysis.

4. Hill, Paul - Paul contacted Dave Easters of Batelle Columbus Labs about satellite repair tools, Mike Davis of Sierracin Magnedyne about literature on a 10-12 lb.-ft. D.C. brushless torque motor, and Mark Withey at ILC Space Systems about specifications on an EVP power tool in EVA tools and equipment catalog. Paul received literature from Inland Motor Co., Aeroflex Motor Co., and Batelle Columbus Labs. Further work included generating graphs of weight vs. torque, torque vs. power, and weight vs. power.

5. Kleinert, Buzz - Buzz worked with Jeff on obtaining specs from library matierials, and working with Doug and Dexter on developing the designs to be put in on GEOMOD for SUPERTAB analysis.

6. Louden, Greg - Greg coordinated with Gayle Garfinkle to finish the commercial library search, in addition to searching for motor specs on the vendor catalogs in the Georgia Tech library.

S C R A M

Progress Report - Week 8 - Group E

Self Contained Robotic Arm Manipulator

Arm Sub-group
Raymond (Buzz) Kleinert
Dexter Edge
Doug Dean

End-effector Sub-group
Jeff Earnest
Greg Louden
Paul Hill

This week, the two sub-groups spent time laying down the final specifications for motors, gearings, and materials in order to prepare our information for a rough draft. More final work remains to be done in order to specify the manner in which the end-effector will be attatched to the wrist segment of the arm.

Other progress made this week includes planning how to assemble all of the information used in generating the report in the format for the final paper. Specification of several arm motors, based on the torque requirements, computing the full work envelope, putting our sketches on CAD, and typing up all the written work are the remaining steps to complete the final paper. Discussion is continuing on making a model of the arm and putting the final presentation together.

1. Edge, Dexter - Dexter worked with the arm group on putting specifications on the arm and motor requirements.
2. Dean, Doug - Doug worked with the arm group on preparing the final specifications for the arm, and wrote and typed this week's progress report,
3. Kleinert, Buzz - Buzz continued the design sketching on CAD, in addition to finalizing arm details for the report.
4. Earnest, Jeff - Jeff worked with the end-effector group on finalizing the motor and torque requirements and specifications, as well as putting together gear specifications.
5. Hill, Paul - Paul worked with the end-effector group on final motor, torque, gear, and power requirements.
6. Louden, Greg - Greg worked with the end-effector group on completing the specifications for the end-effector, in addition to work on the computer simulation for the final presentation.

APPENDIX B

R

CHARACTERISTICS OF DC BRUSHLESS MOTORS TABLE 1

AEROFLEX LABS MOTOR SPECS

WEIGHT (lb)	PEAK TORQUE (ft-lb)	CONT. TORQUE (ft-lb)	PEAK POWER (watts)	CONT. POWER (watts)
5	2.6	1	250	40
5	1.25	1.1	152	75
8	3.3	1.6	170	43
10	4.2	1.5	270	36
10	4.2	1.5	300	39
12	4	2.5	450	174
16	4.2	2.4	230	91
16	4.5	3.3	230	127
19	7	4.5	350	150
27	7.8	5.1	350	150
49	22	18	375	178
60	18	17	580	500

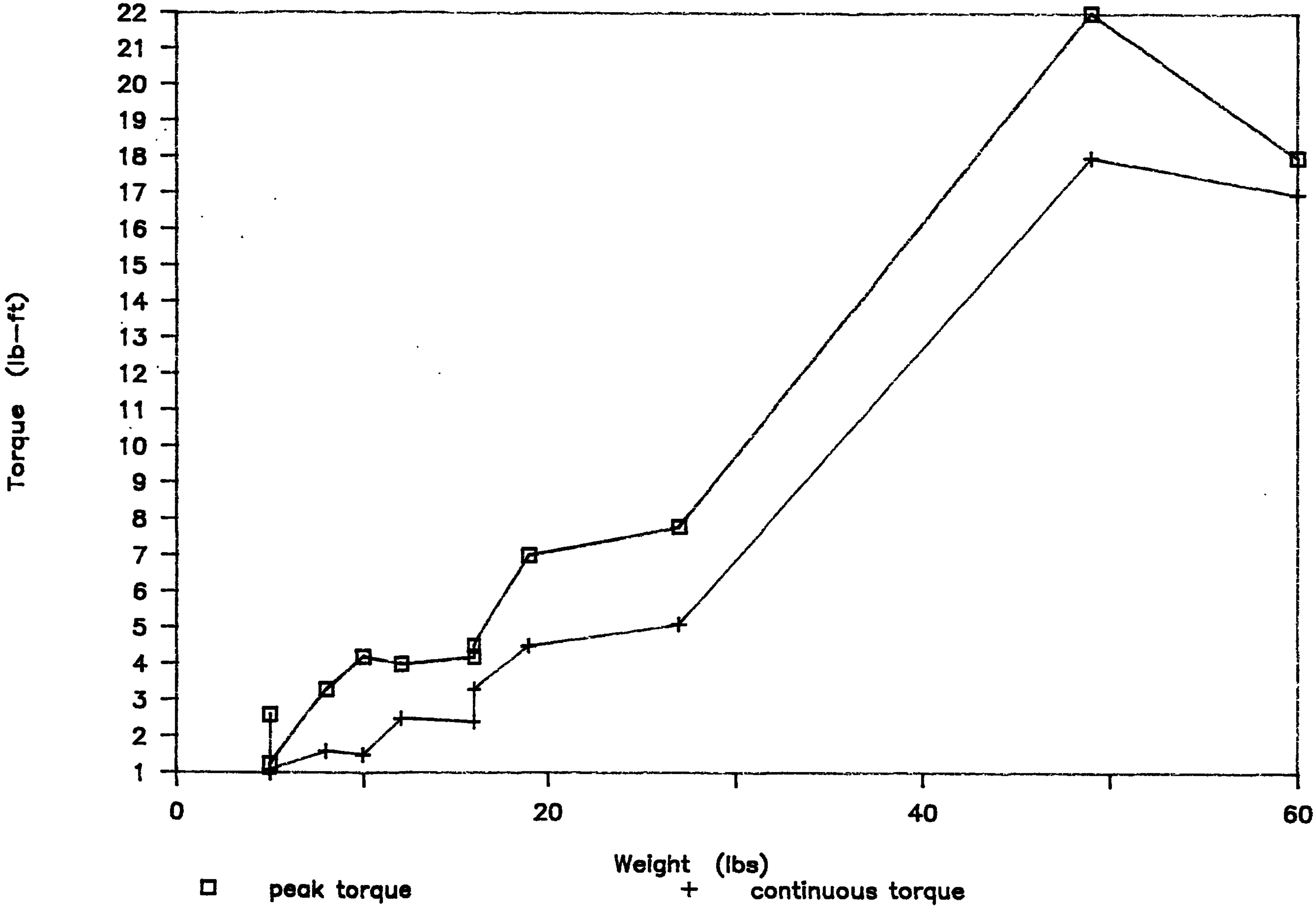
INLAND MOTOR SPECS

WEIGHT (lb)	PEAK TORQUE (lb-ft)	POWER (watts)
4	3.4	212
7	3.4	190
8	7.8	360
14.6	10.3	1100
22.5	23.4	700

ALL MOTORS WITHIN REQUIRED TEMPERATURE RANGES

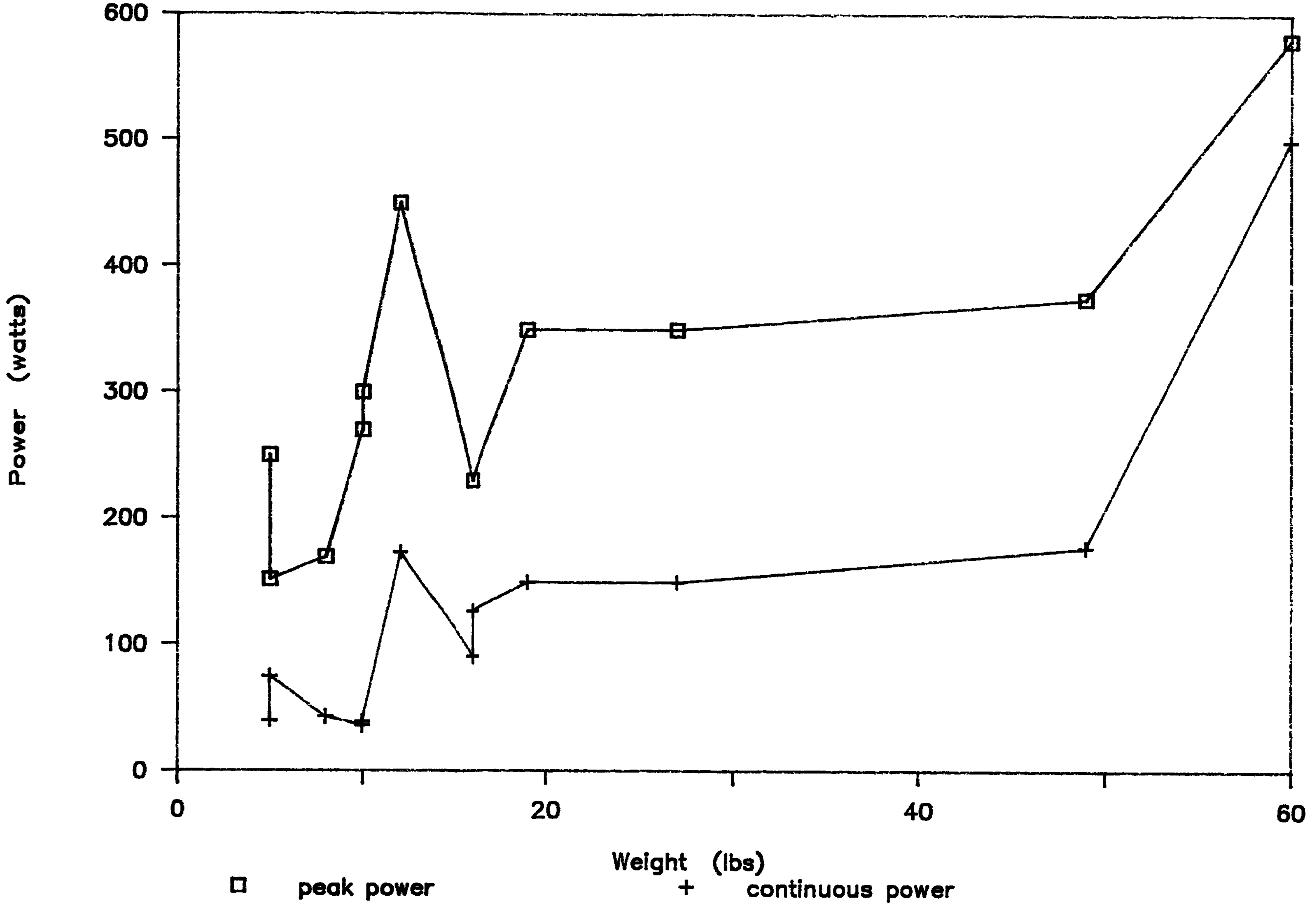
MOTOR CHARACTERISTICS

FIGURE 1 AEROFLEX LABS



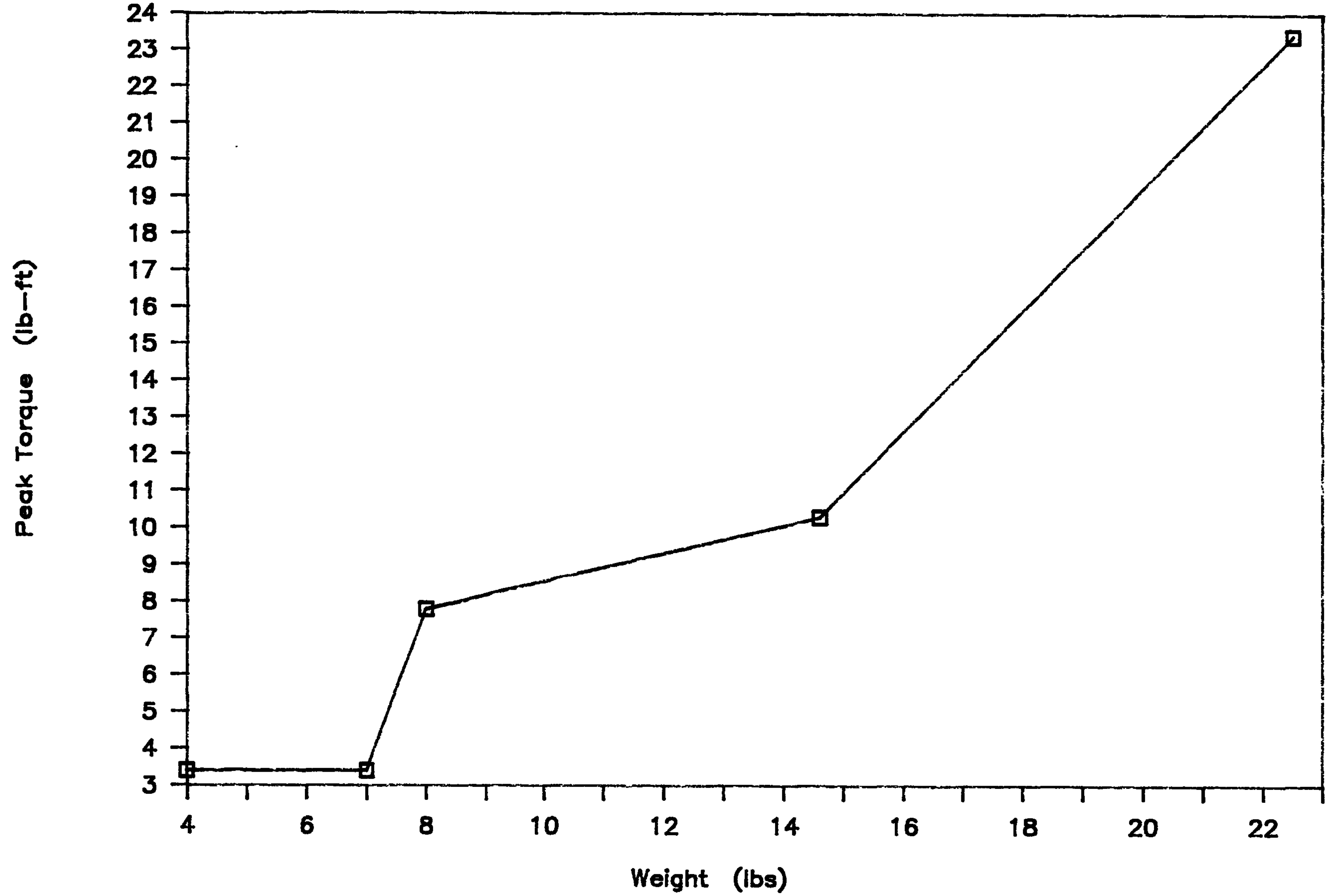
MOTOR CHARACTERISTICS

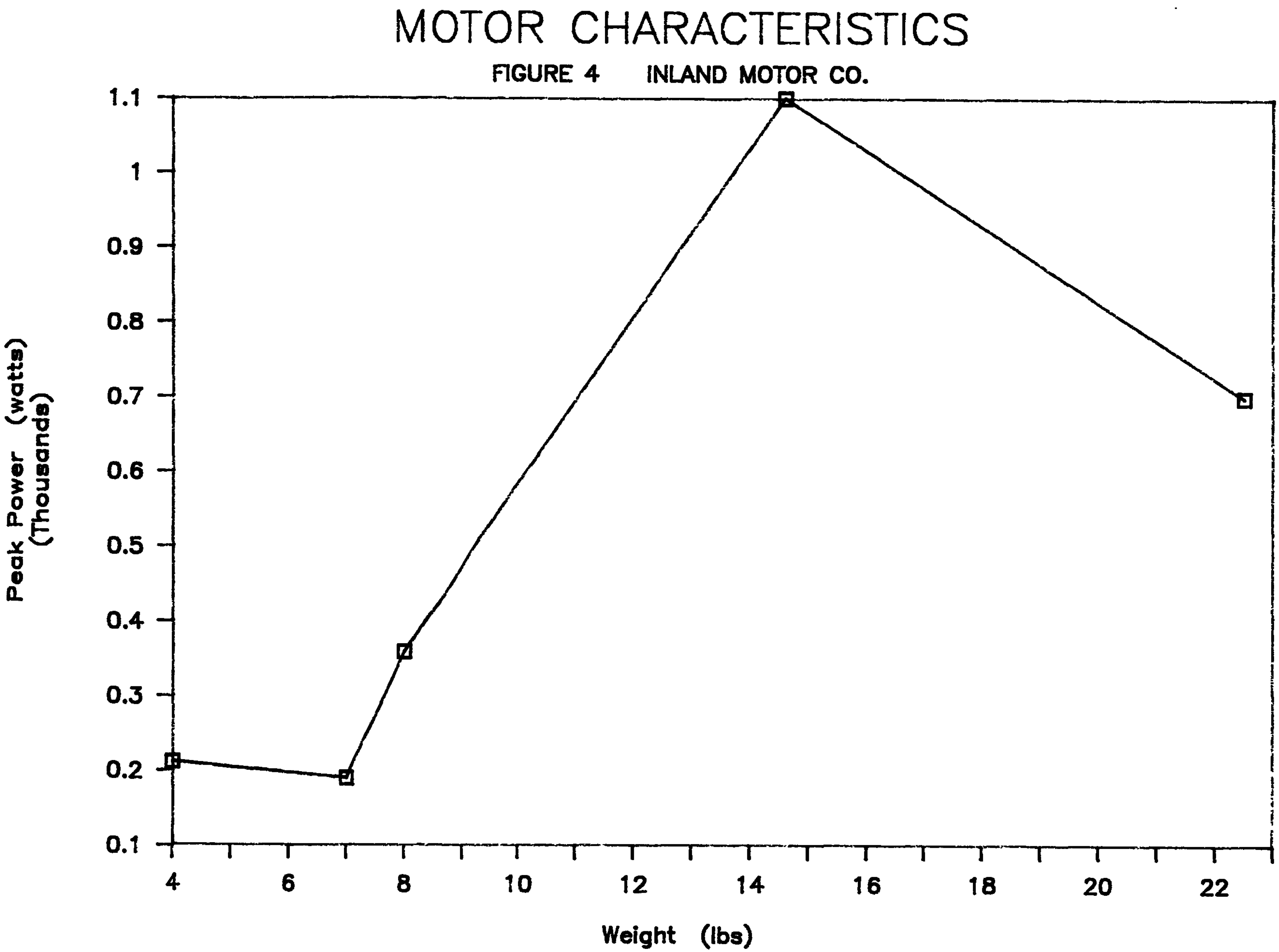
FIGURE 2 AEROFLEX LABS



MOTOR CHARACTERISTICS

FIGURE 3 INLAND MOTOR CO.

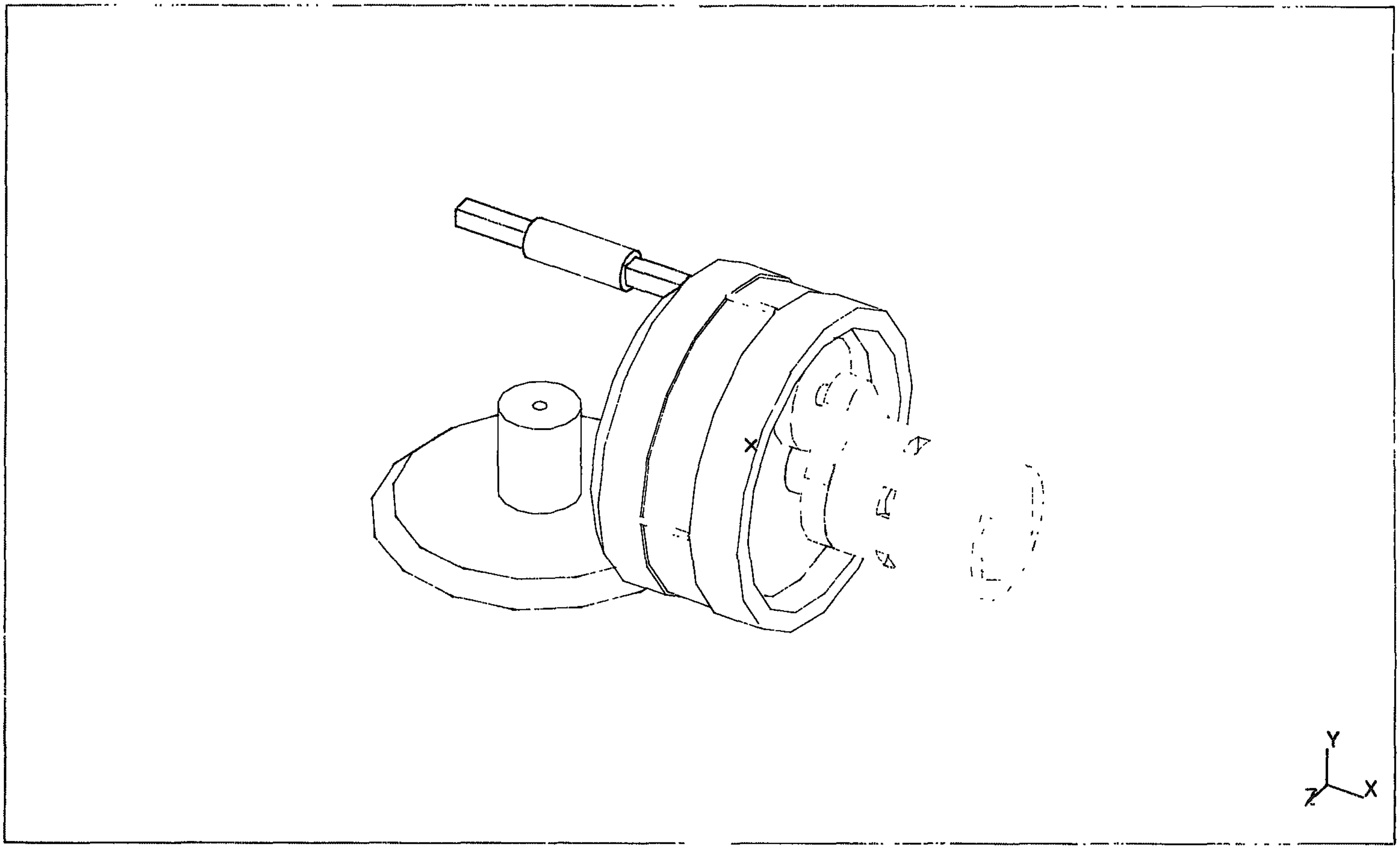



MOTOR CHARACTERISTICS
FIGURE 4 INLAND MOTOR CO.
Peak Power (watts)
(Thousands)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
4
6
8
10
12
14
16
18
20
22
Weight (lbs)

APPENDIX C

FOLDOUT FRAME 1.

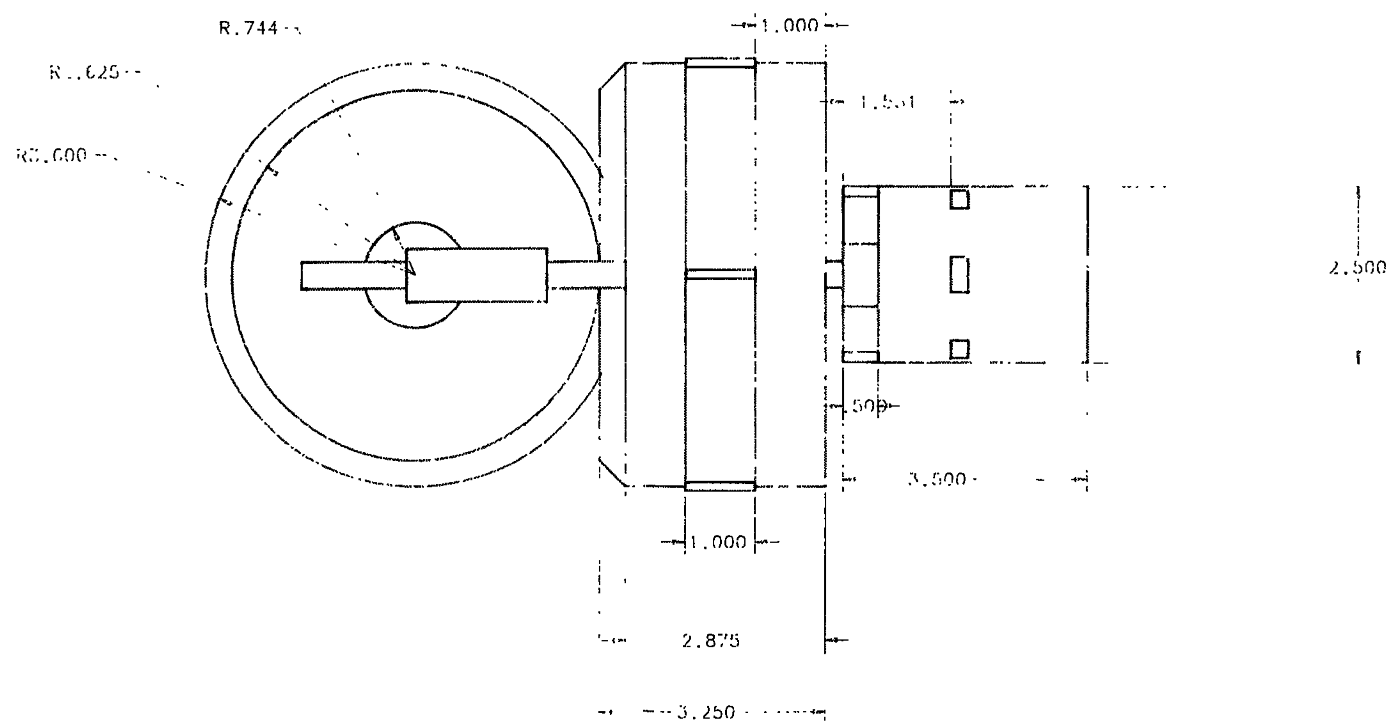
FOLDOUT FRAME 2



FOLDOUT FRAME /

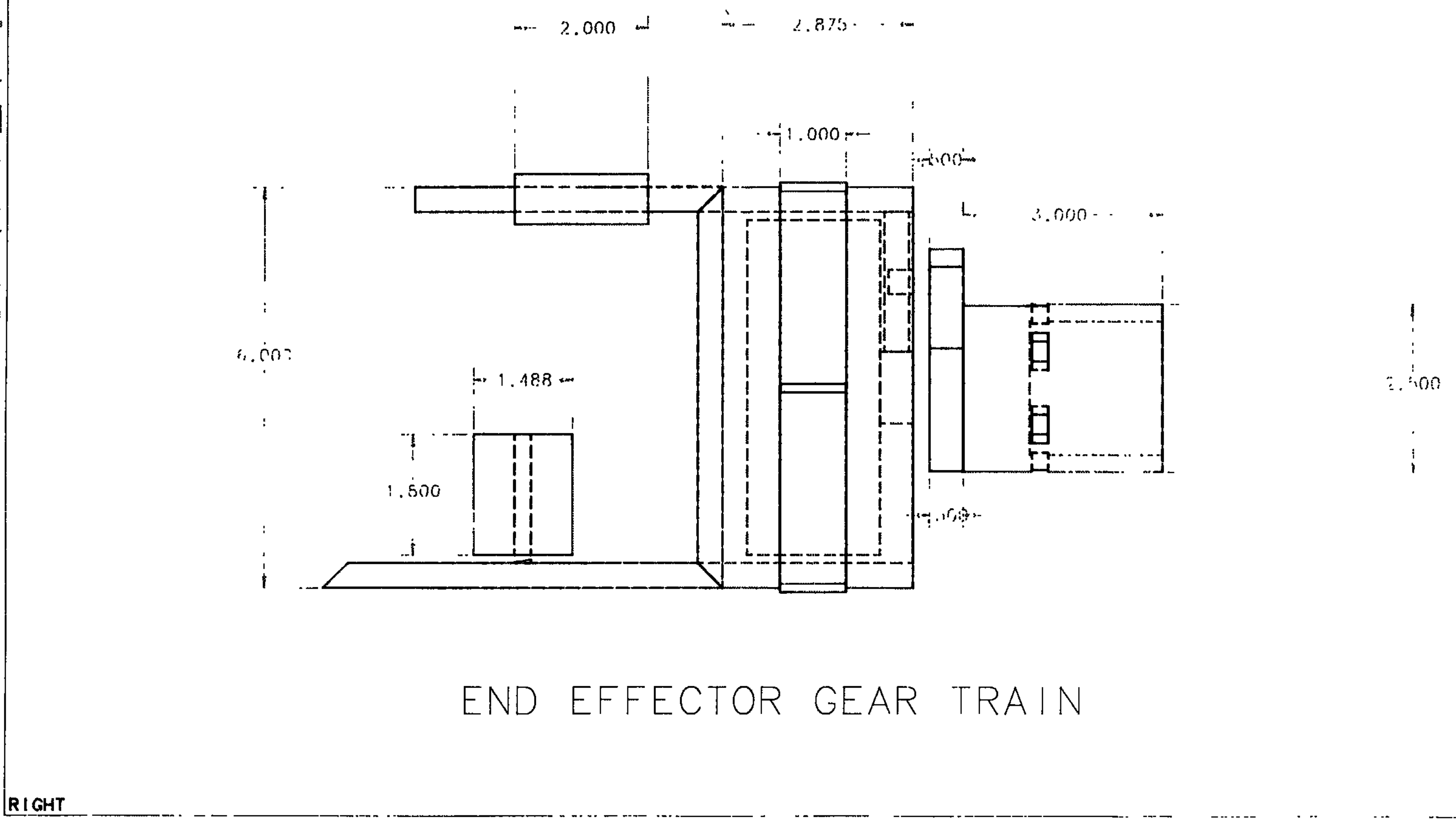
FOLDOUT FRAME 2

END EFFECTOR GEAR TRAIN



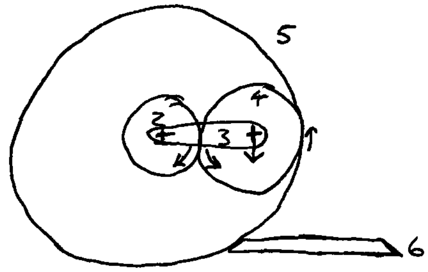
FOLDOUT FRAME /

FOLDOUT FRAME 2



END EFFECTOR GEAR TRAIN

d = gear diam
n = speed rpm
w_t = transmitted load
H = power



Planetary Gear Train

$$\frac{n_5}{n_2} = \frac{n_5 - n_3}{n_2 - n_3}$$

$$e = -\frac{\#\text{Teeth on Sun}}{\#\text{Teeth on Ring}} = \frac{d_2}{d_5} \qquad n \sim d$$

Need torque range of 1 – 20 ft/lb.

Torque in is 3.4 ft/lb @ 5,000 RPM BM-3701 Inland

$P = T\omega$ <u>Peak Torque when $n_5 = 0$</u> $T = 20$ ft-lb

$$P_{in} = 3.4\text{ ft-lb }(5{,}000\text{ RPM})(2\pi/60\text{ rad/s/rpm}) = 1780\text{ ft-lb/s}$$

$$\omega_{OUT} = \frac{P}{T} = \frac{1780}{20} = 89\text{ rad/s} = 850\text{ RPM}$$

$$-e = \frac{n_5 - n_3}{n_2 - n_3} = \frac{0 - 850}{(5000 - 850)} \qquad e = .2048$$

$$d_2 + 2d_4 = d_5$$

size of motor: 5" OD
2" L

$$.2048\, d_5 + 2d_4 = d_5 \qquad d_5 = 5.25''$$
$$d_2 = .2048\, d_5 = 1.0763''$$

Low Torque = 1 ft-lb

$$P_{in} = 212\text{ W }(.737)\frac{\text{lbf-ft}}{\text{W s}} = 156.24\text{ lbf-ft/s}$$

$$P = T\omega$$
$$\omega = P/T = \frac{156.24}{1} = 156.24\text{ rad/s} = 1{,}491.9\text{ RPM}$$

$$-.205 = \frac{N_5 - 1491.9}{438 - 1491.9} \qquad N_5 = 1{,}707\text{ RPM}$$

$$e\text{ of bevel mating} = \frac{d_5}{d_6} = \frac{5.625''}{6''} = .9375$$

$$P_{in} = .4(156.24\text{ lbf-ft/s}) = 62.50\text{ ft-lb/s} = 85.96\text{ W}$$

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OF POOR QUALITY

$N_6 = e N_5 = .9375\,(1707) = 1603$ RPM

$1603\left(\frac{2\pi}{60}\right) = 168$ rad/s

$$\text{Torque} = \frac{62.50}{168} = .3723 \text{ ft-lb @ } 1600 \text{ RPM}$$

$$\simeq 72 \text{ oz-in}$$

$$\frac{72 \text{ oz in}}{\sqrt{85.96\,W}} = 7.76 \text{ oz in}/\sqrt{\text{WATT}}$$

Inland Model BM-0702 produces 7.8 oz-in/$\sqrt{\text{WATT}}$

APPENDIX D

WEIGHT CALCULATIONS

	SURFACE AREA (IN^2)	VOLUME (IN^3)	DENSITY lb/in^3	MASS
PLANETARY GEARS	10.05623	1.317252	.282	.3714651
RING GEAR	126.3234	18.66180	.282	5.262629
BEVEL GEAR	57.87121	9.094712	.282	2.564709
SUN GEAR & SHAFT	10.17226	2.217226	.282	.650655
TOTALS	204.423	31.291	.282	12.17 lb

THE WEIGHT OF THE GEARS WAS CALCULATED USING A SOLID DISC AS A GEAR. DUE TO SLOTTING OF GEARS AND GEAR TEETH IT WAS DECIDED THAT 60% OF THE CALCULATED WEIGHT WAS SUFFICIENT TO ESTIMATE THE WEIGHT FOR THE GEARS

$$12.17 \text{ lb} \times .6 = \underline{7.3 \text{ lb}}$$

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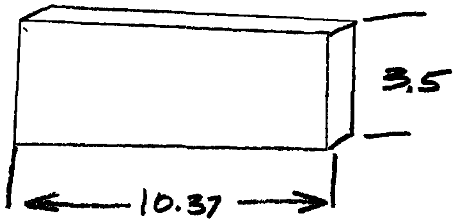
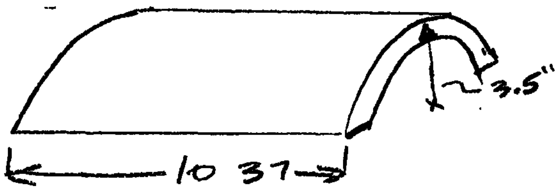
OF POOR QUALITY

Housing

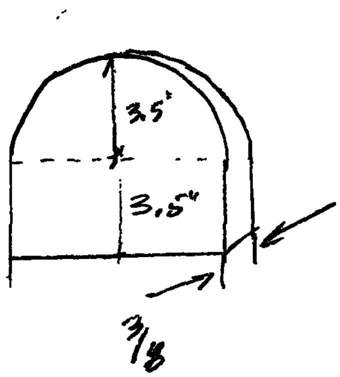
MASS



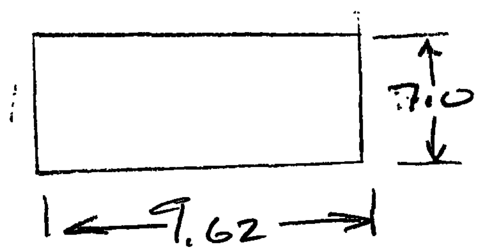
2 SIDE PIECES @ 13.611 in³ — 2.722 lb



1 TOP @ 40.468 in³ — 4.641



2 END @ 16.403 in³ — 3.281 lb



1 BOTTOM @ 25.253 — 2.5253

13.175

Motor supports & Housings

4 EQUAL ANGLE 6' LONG @ .28 lb/foot — 1.6 lb

1 MOTOR SUPPORT PLATE @ 10.603 in³ = 1.0603 lb

TOTAL 14.797

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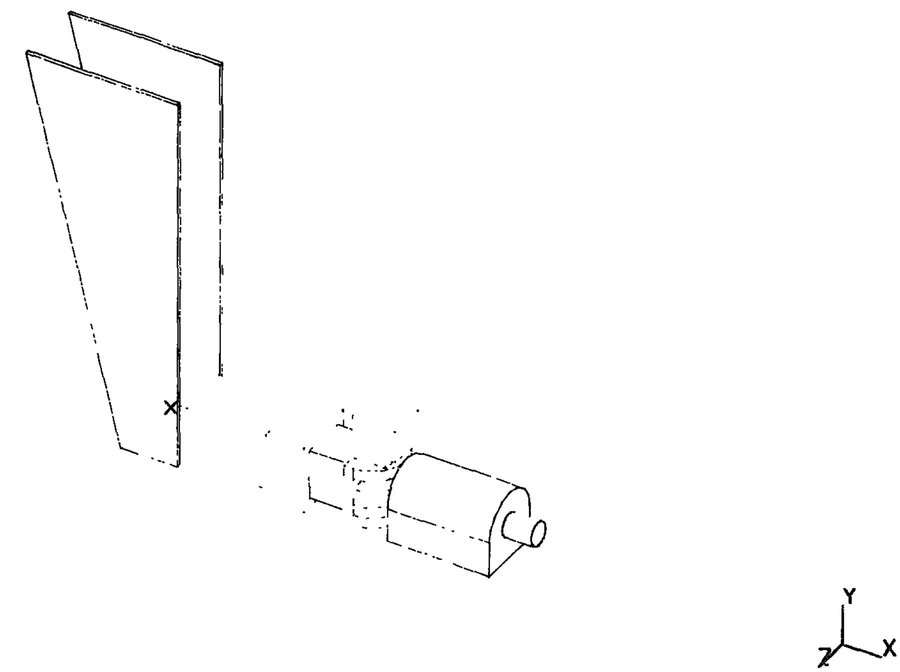
APPENDIX E

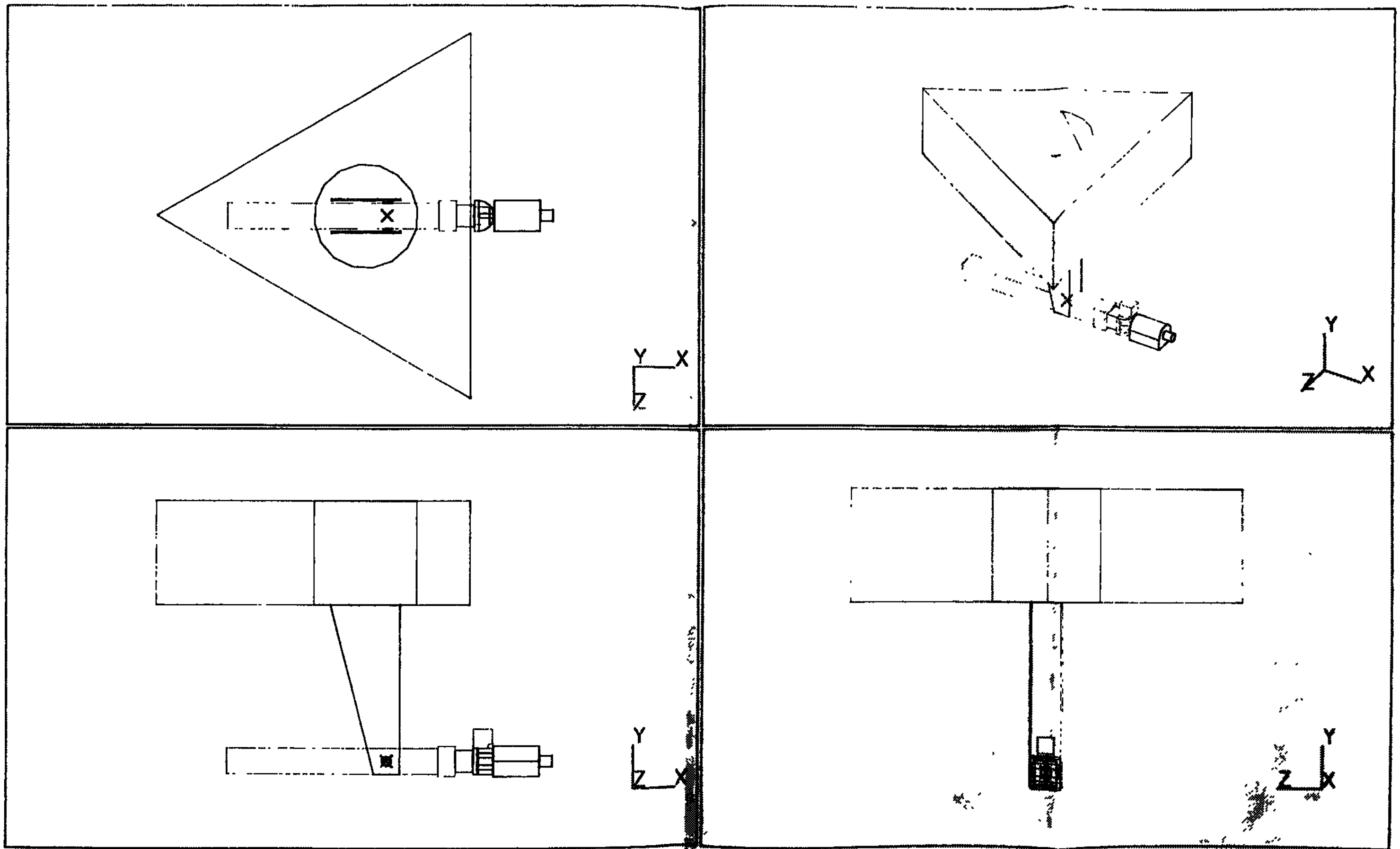
FOLDOUT FRAME /

FOLDOUT FRAME 2



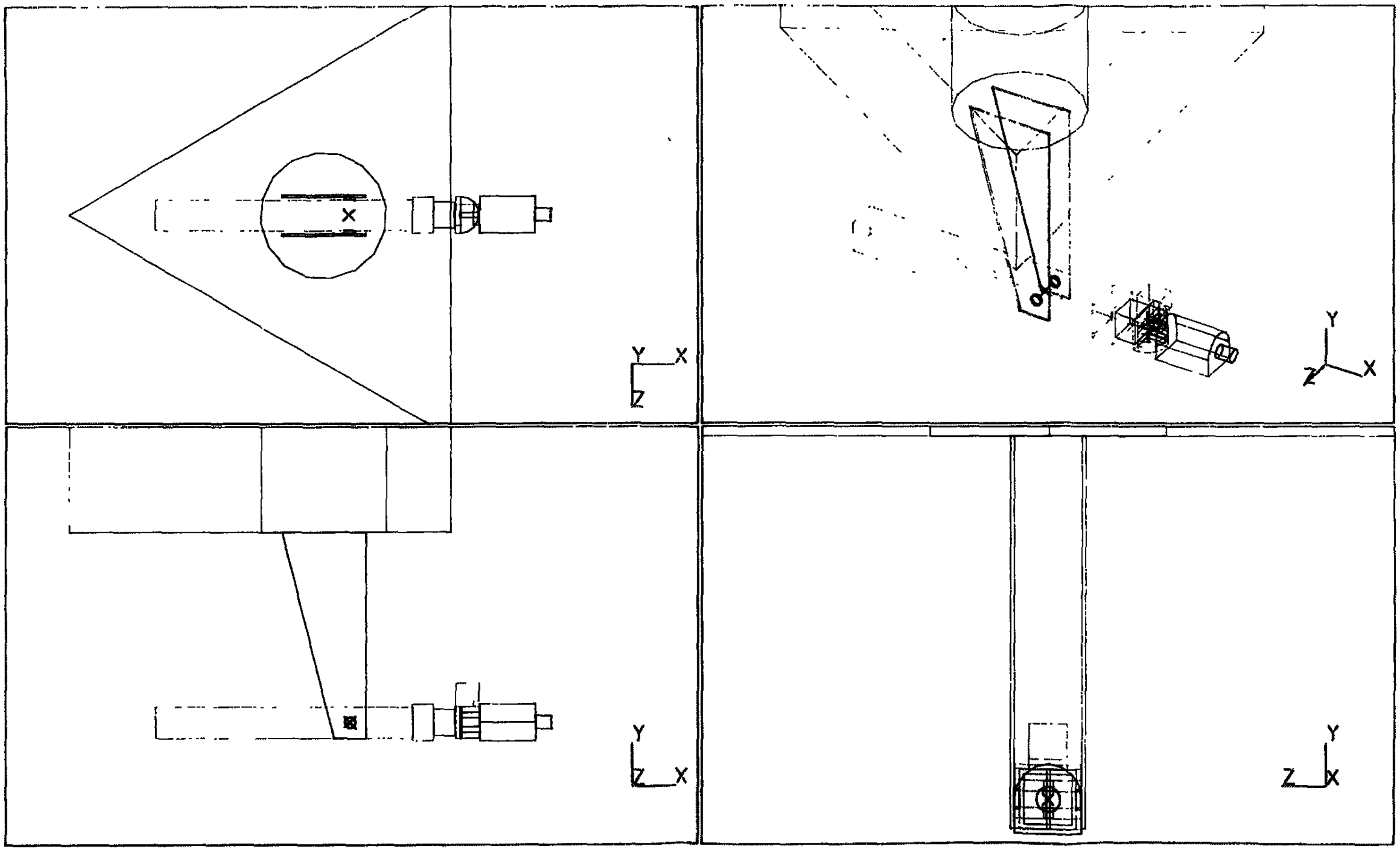
FOLDOUT FRAME 1.

FOLDOUT FRAME 2



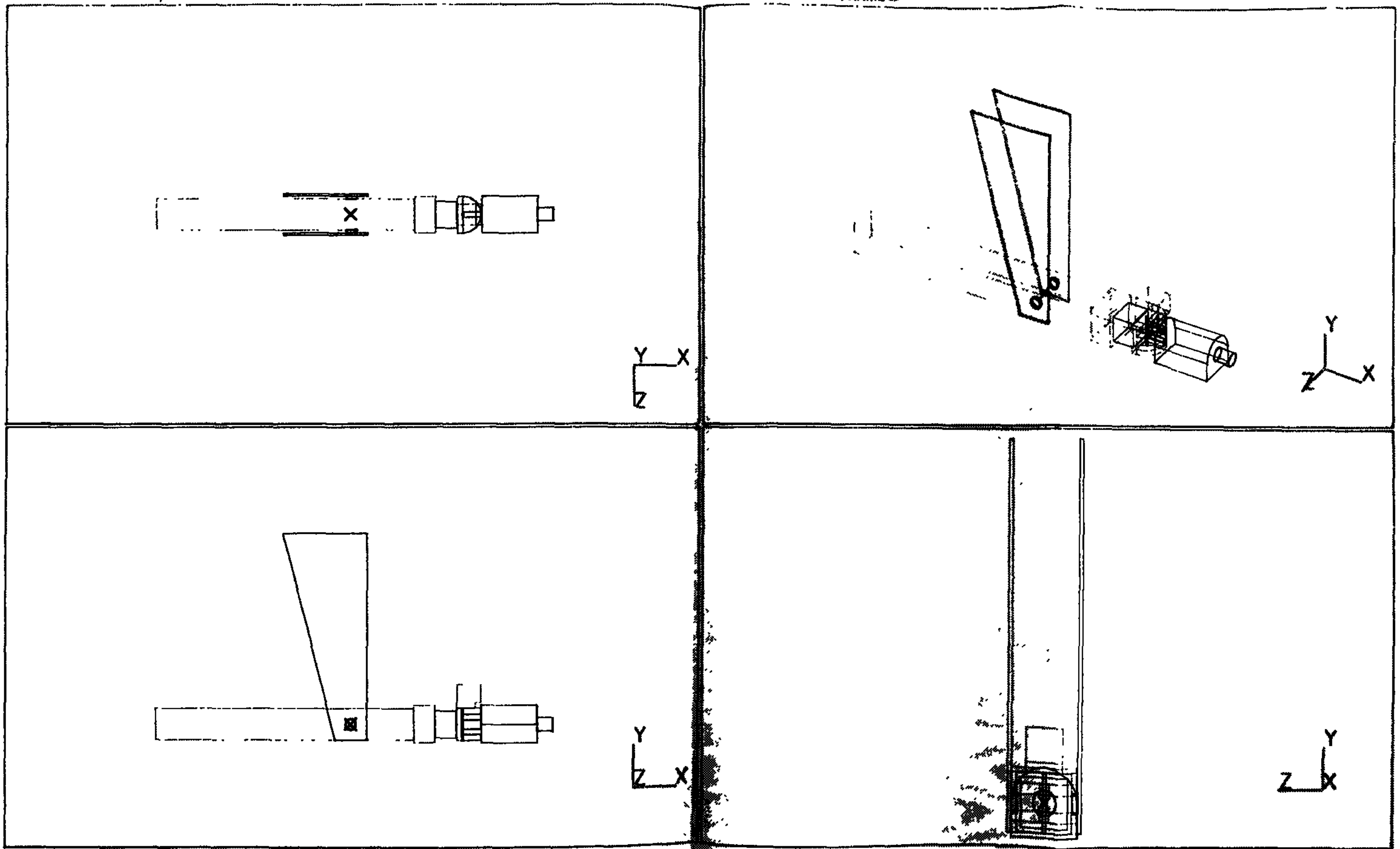
FOLDOUT FRAME 1

FOLDOUT FRAME 2.



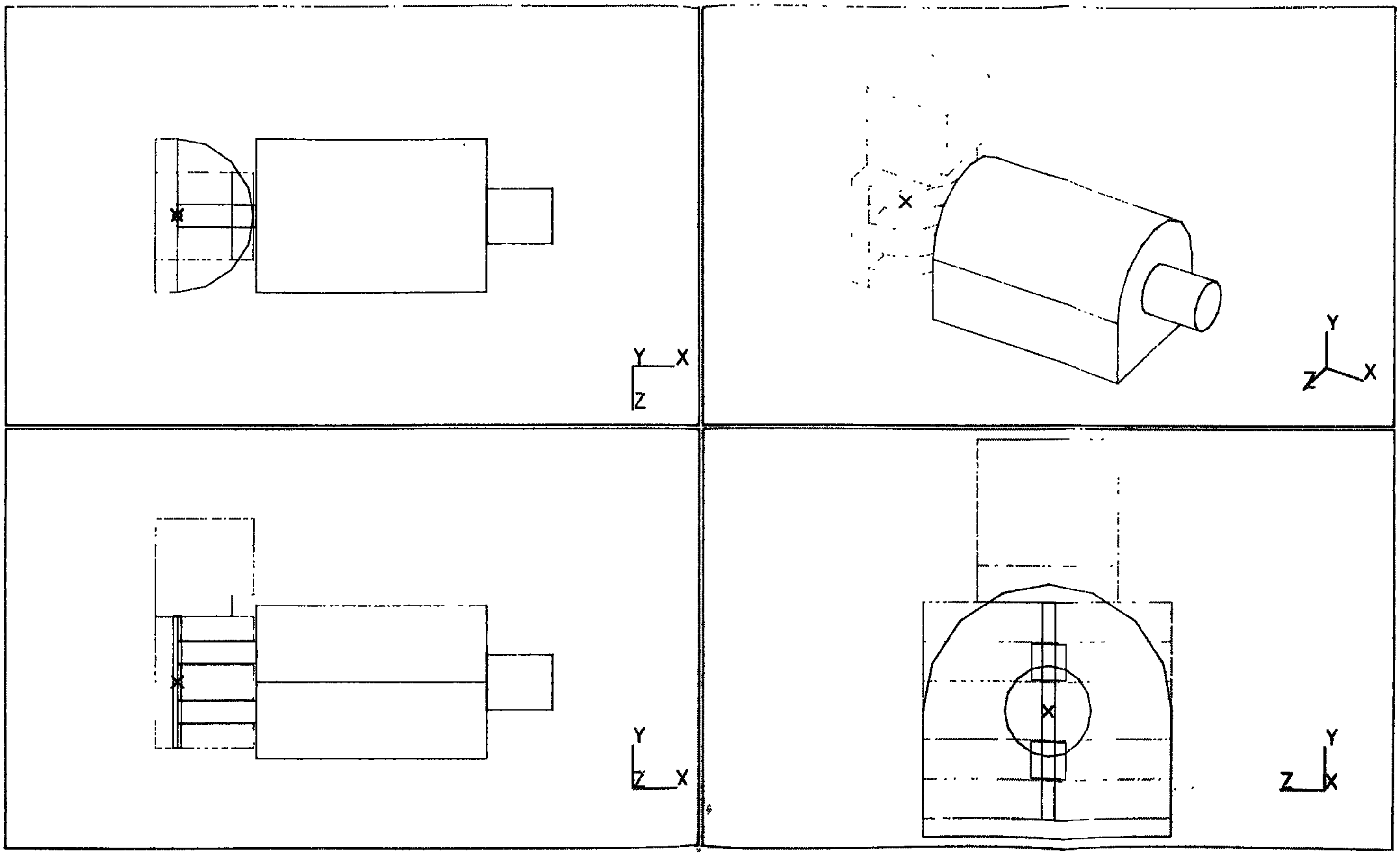
FOLDOUT FRAME 1

FOLDOUT FRAME 2



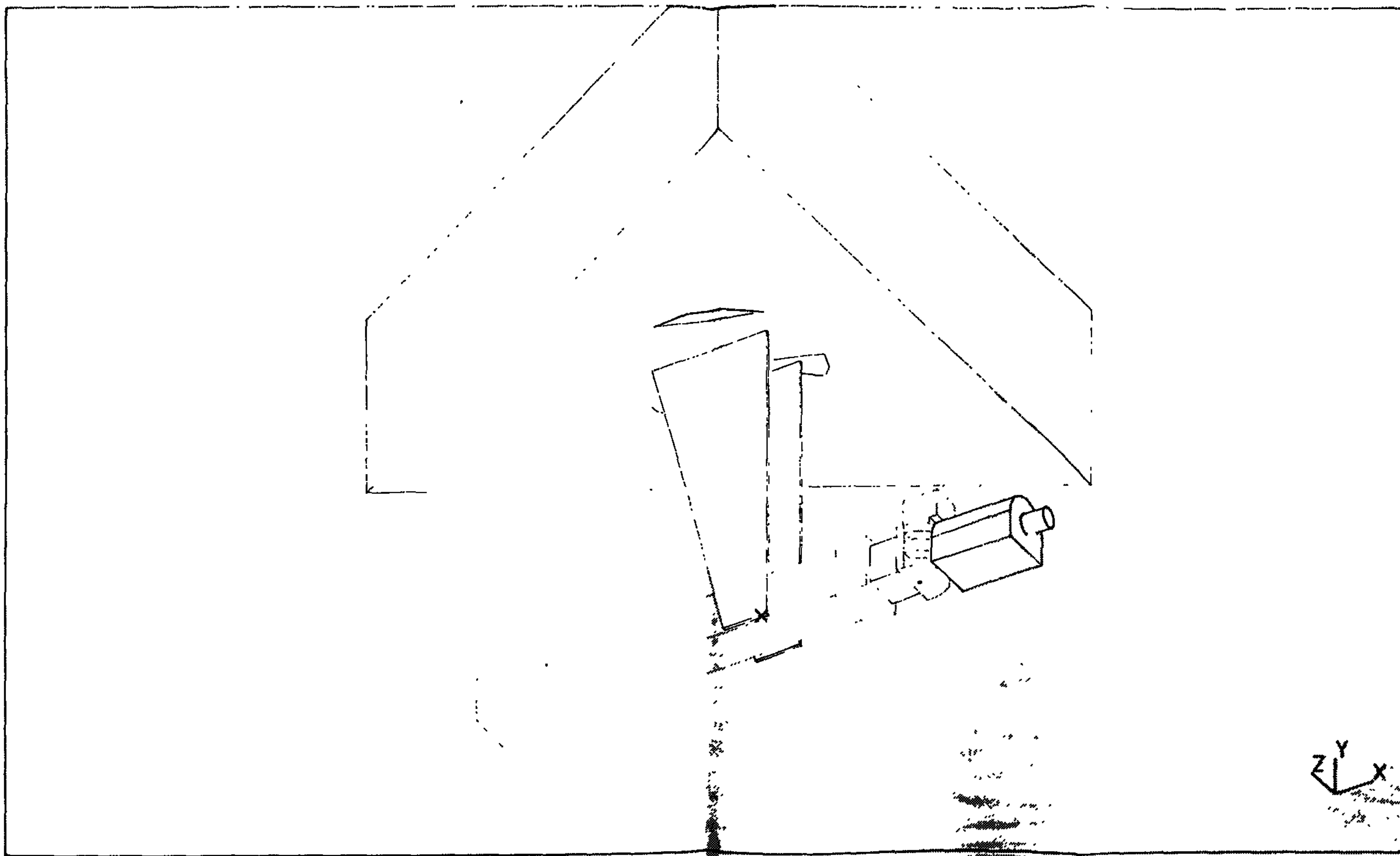
FOLDOUT FRAME 1

FOLDOUT FRAME 2.

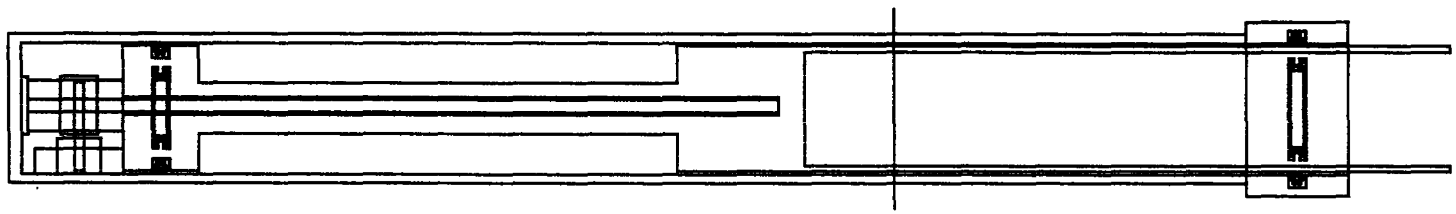


FOLDOUT FRAME 1.

FOLDOUT FRAME 2

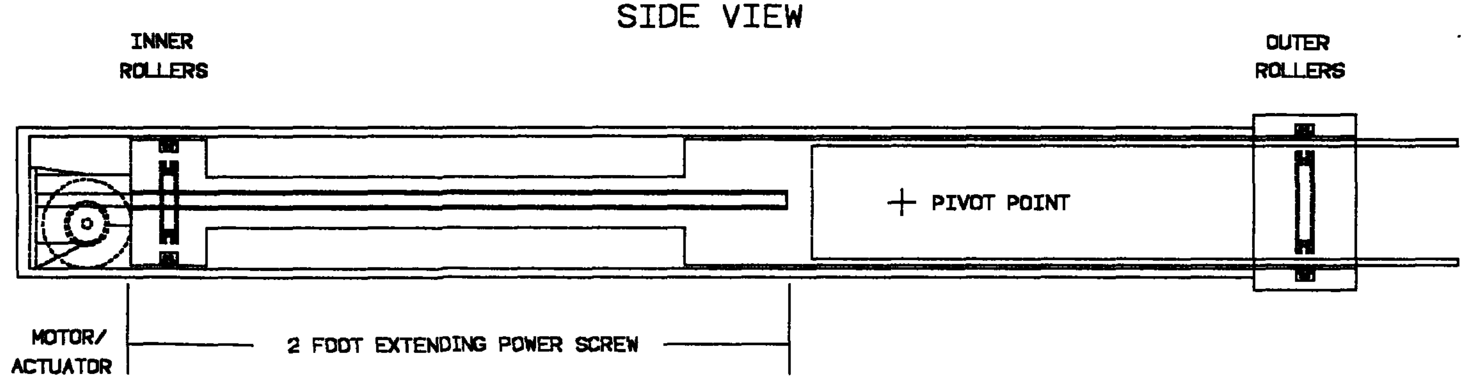


TELESCOPING ARM DESIGN



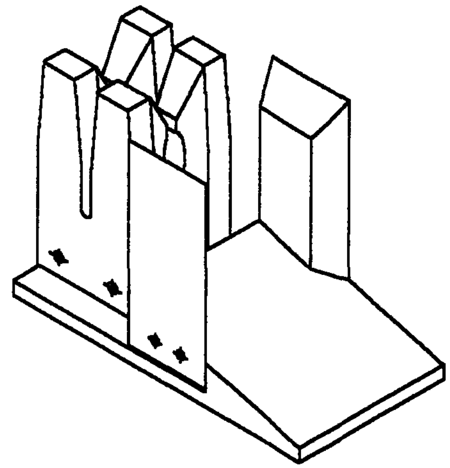
TOP VIEW

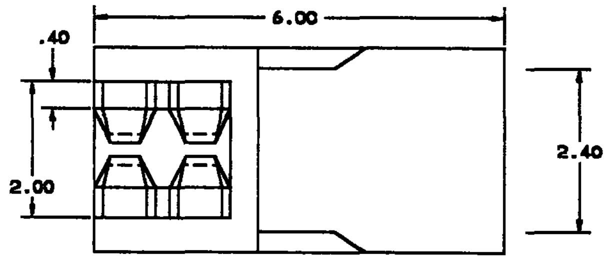
SIDE VIEW



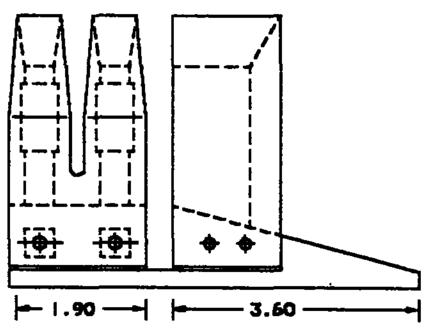
APPENDIX F

INTERCHANGEABLE - TOOL RACK

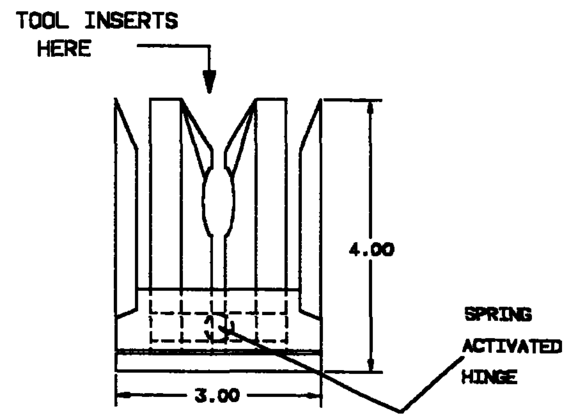




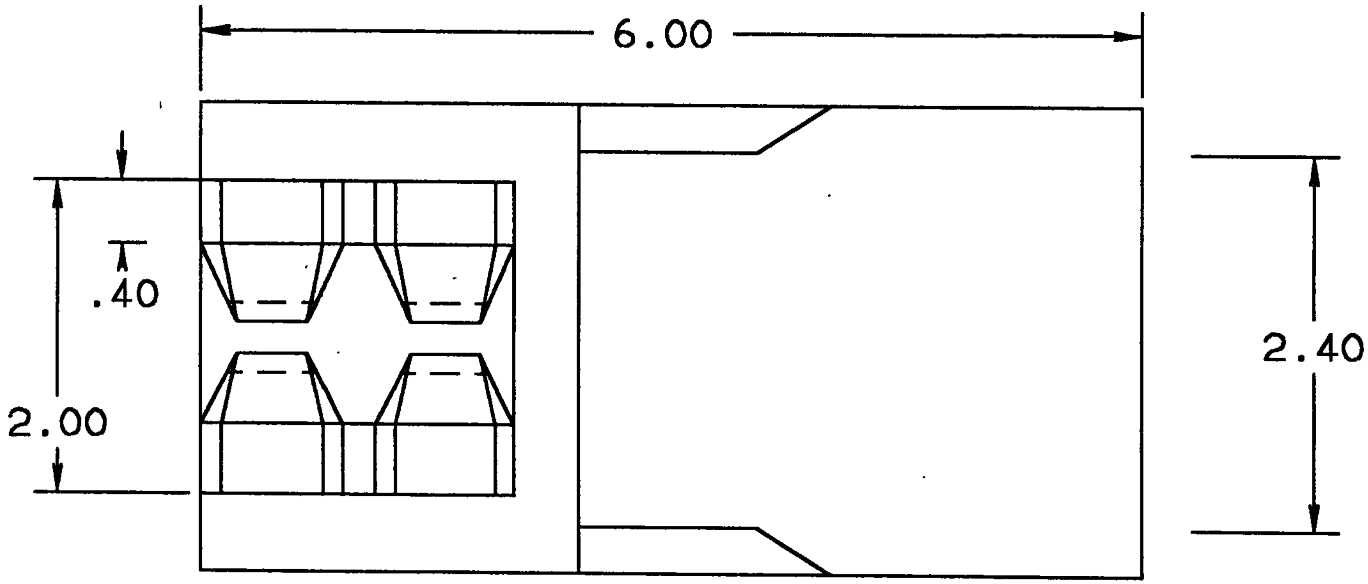
TOP VIEW



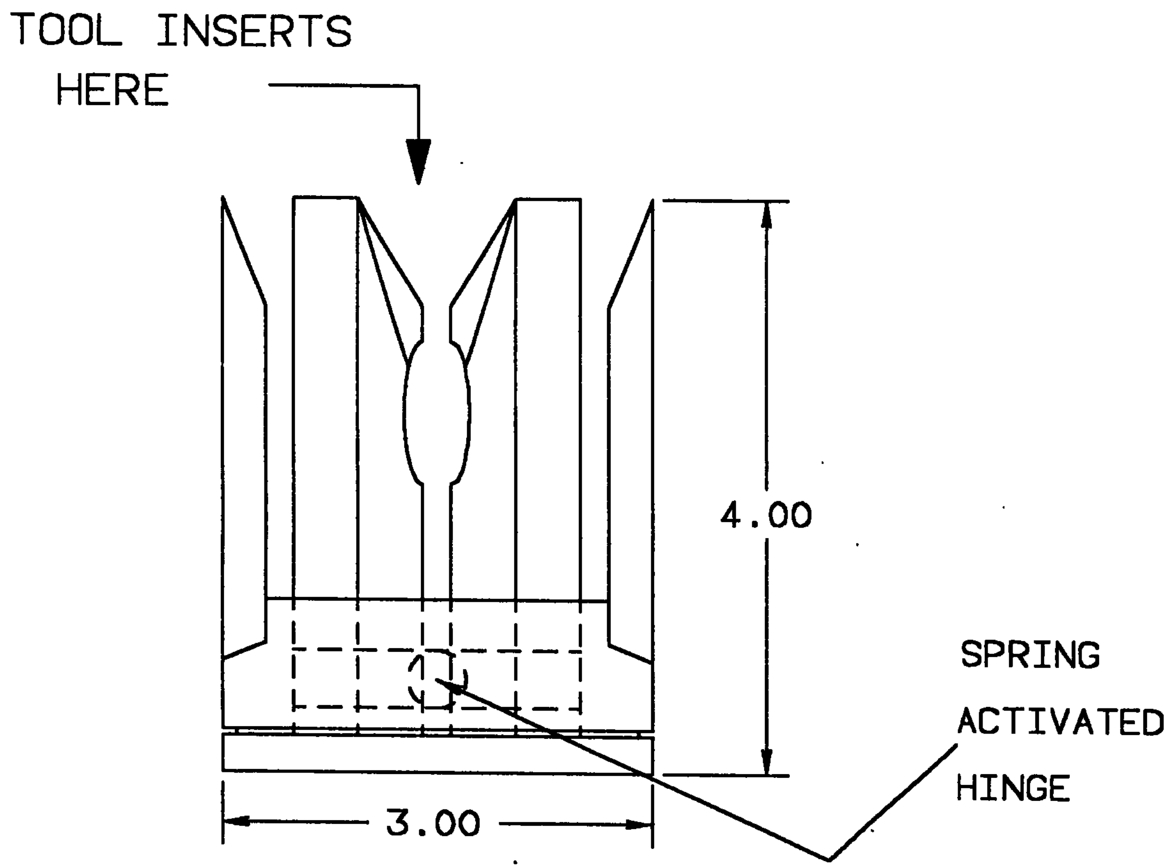
SIDE VIEW



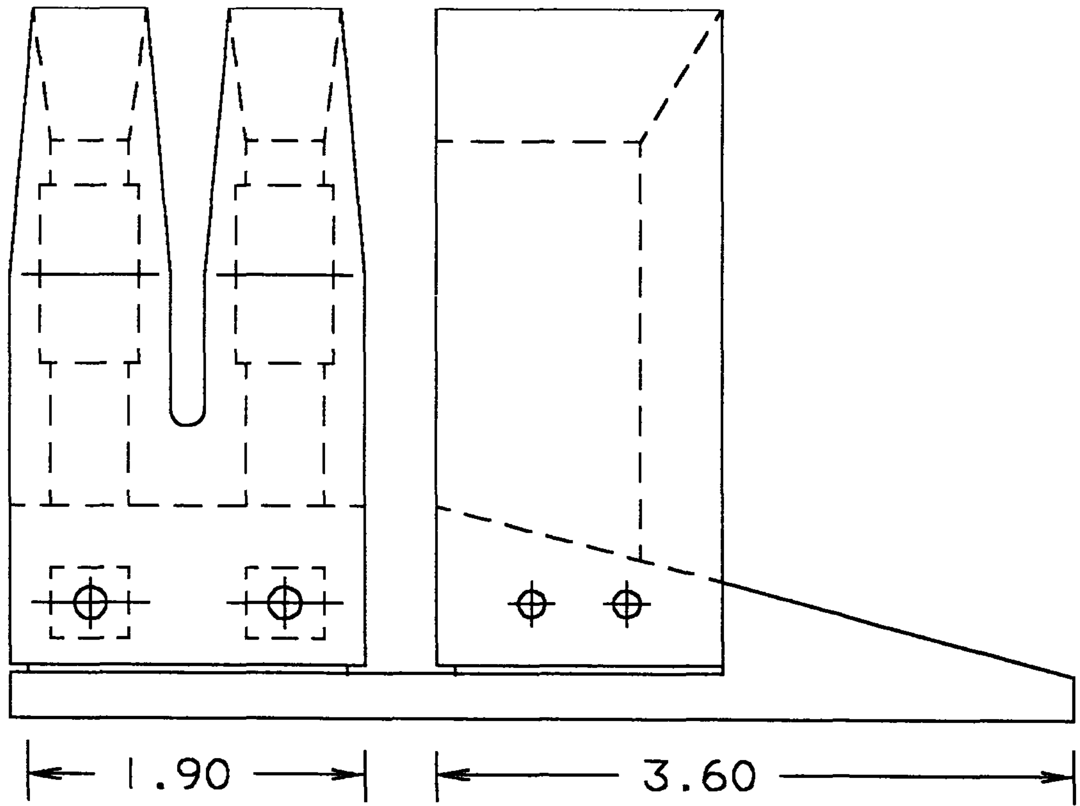
FRONT VIEW



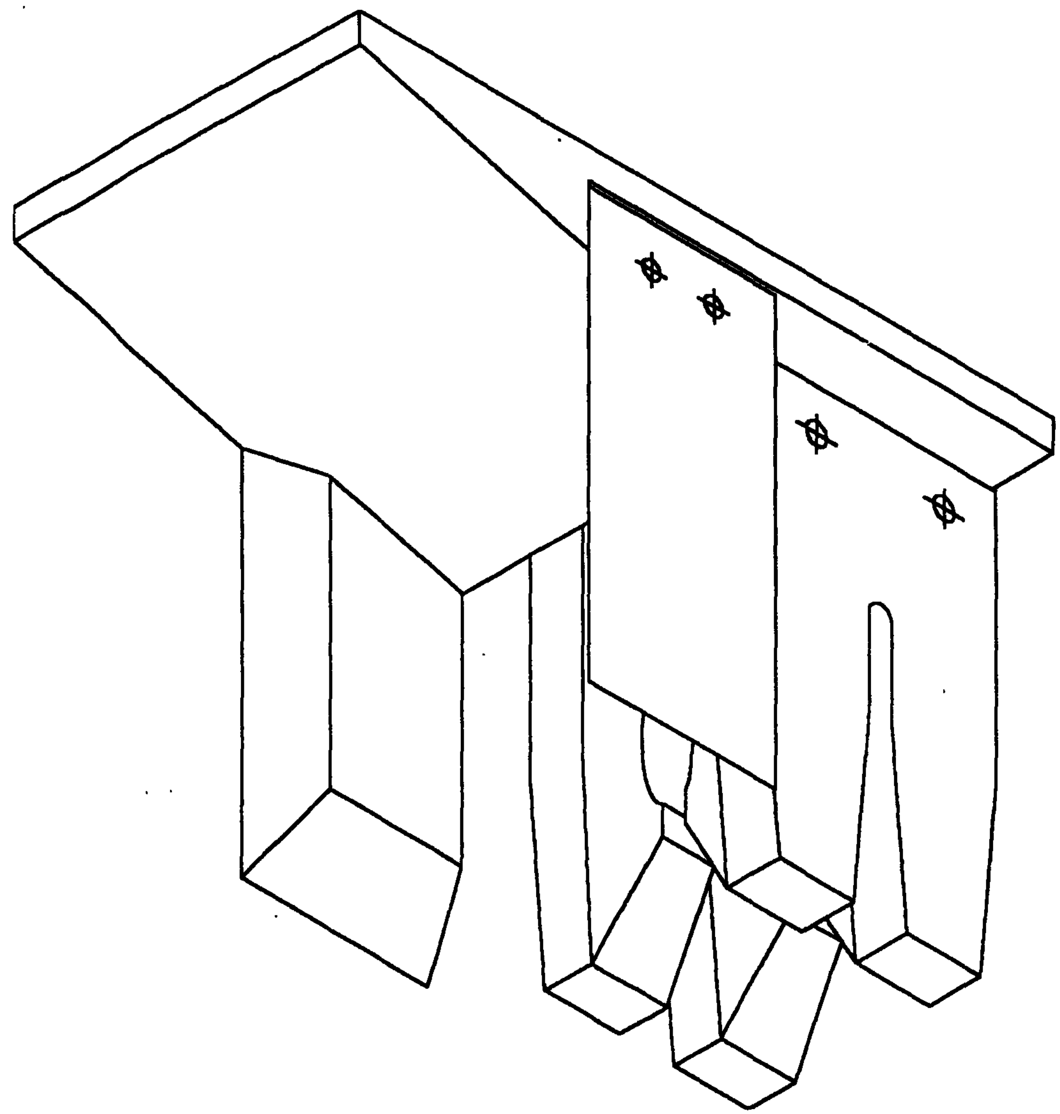
TOP VIEW



FRONT VIEW



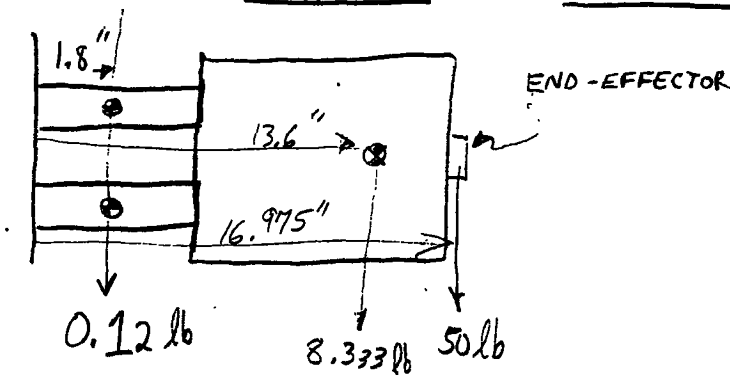
SIDE VIEW



2-2

APPENDIX G

WRIST DESIGN



STATIC TORQUE: $0.12(1.8") + 8.333(13.6") + 50(16.975")$
$= 80.191611$ ft-lb

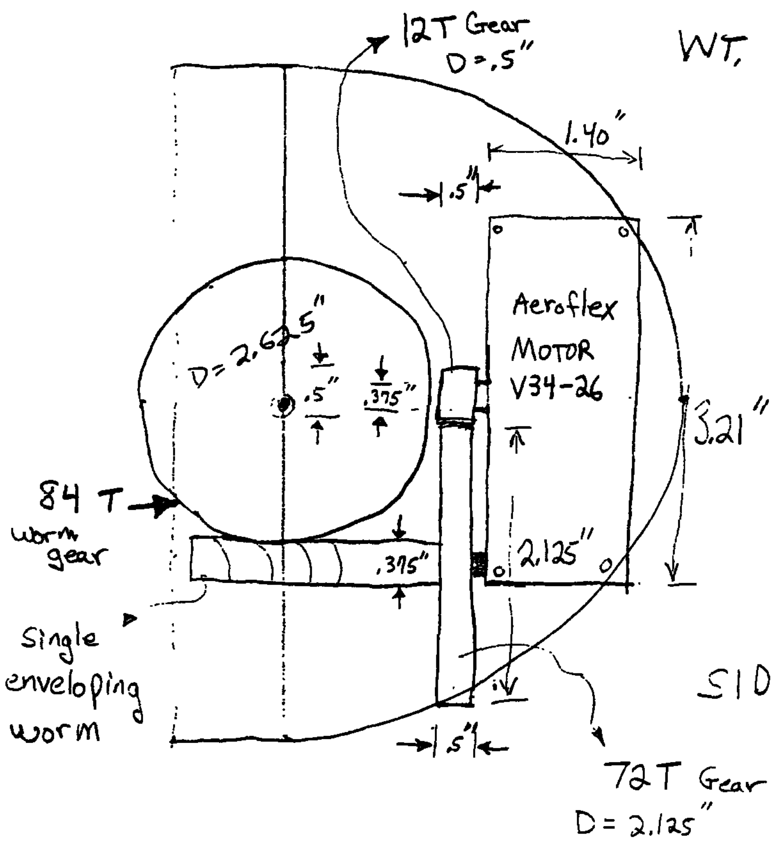
utilizing a 250:1 Gear Ratio,
TORQUE REQUIRED is 61.587157 oz-in

SO, SPEC. AN AEROFLEX V34-26 MOTOR.

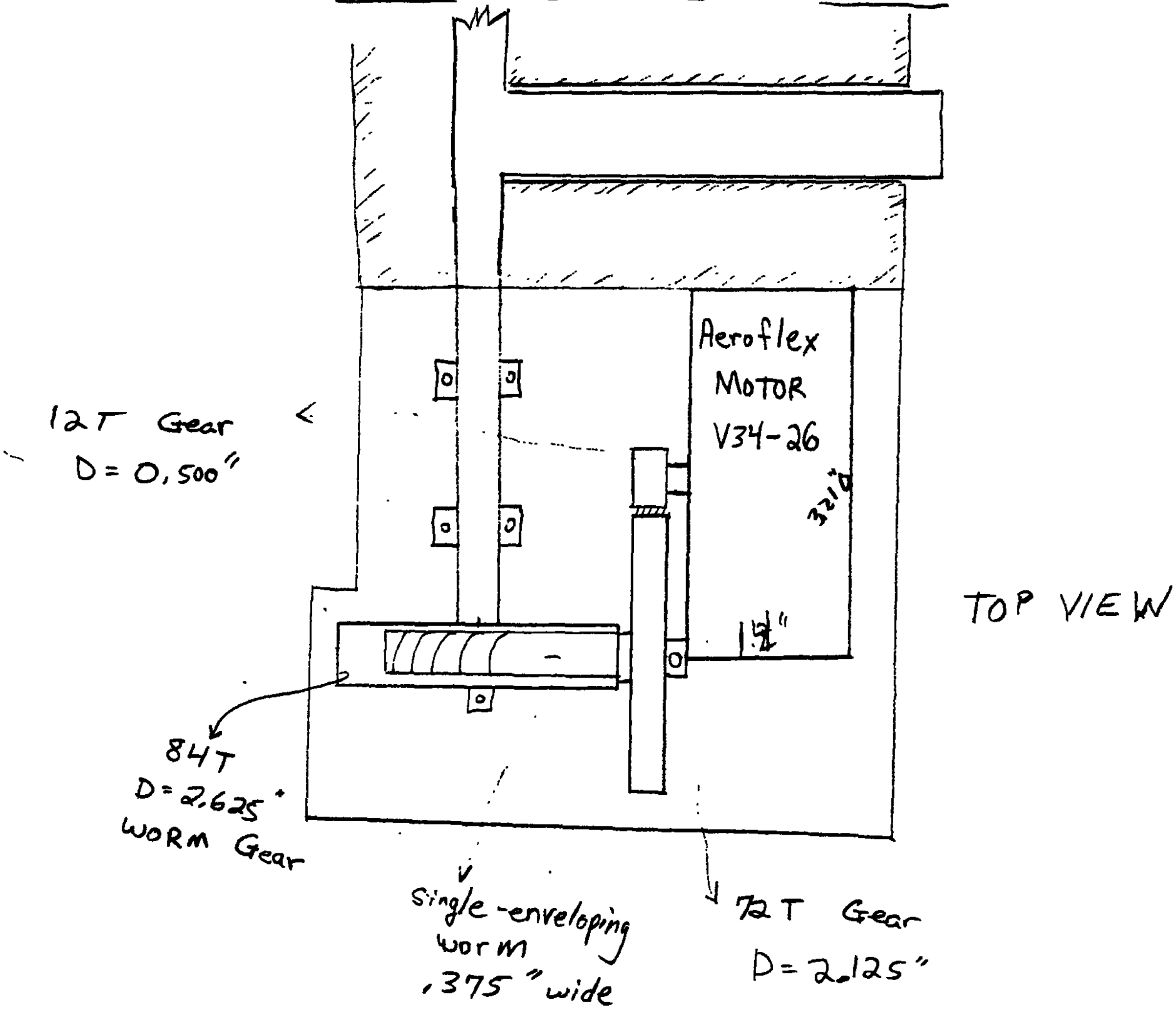
PEAK TORQUE: 180 oz-in @ 1728 RPM (230 watts)

CONTINUOUS TORQUE: 86 oz-in @ 786 RPM (50 watts)

WT. 30 oz



WRIST DESIGN (CONT'D)



Motor Weight – Aeroflex Book – 30 oz = 1.875 lb.

Gear train weight – steel gears

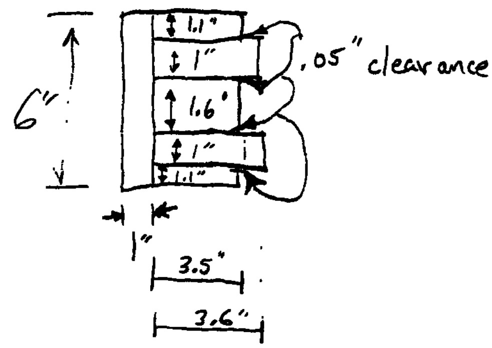
$\pi\left(\frac{2.625}{2}\right)^2 .5 = 2.706\ in^3$ $\quad \pi\left(2.125/2\right)^2 .5 = 1.774\ in^3$ $\quad \pi\left(\frac{2.500}{2}\right)^2 .5 = 1.841\ in^3$ $\quad \pi\left(\frac{.5}{2}\right)^2 .5 = .098\ in^3$

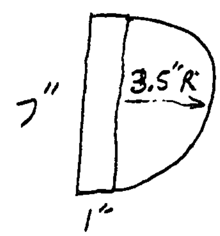
total = $6.4192\ in^3$

$$6.4192\ in^3 \cdot \left(\frac{.280\ lb}{in^3}\right)_{steel} = 1.797\ lb$$

WRIST DESIGN (CONT'D)

Weight of

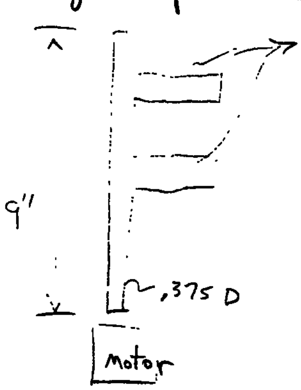




$$\frac{1}{2}\pi(3.5)^2 6 + (7\times 6\times 1) - \left(\frac{.375}{2}\right)^2 6\pi - \pi(3.5)^2 1.1$$

$$= 202.9723 \text{ in}^3 \cdot \left(\frac{.100 \text{ lb}}{\text{in}^3}\right)_{Al} = 20.29723 \text{ lb}$$

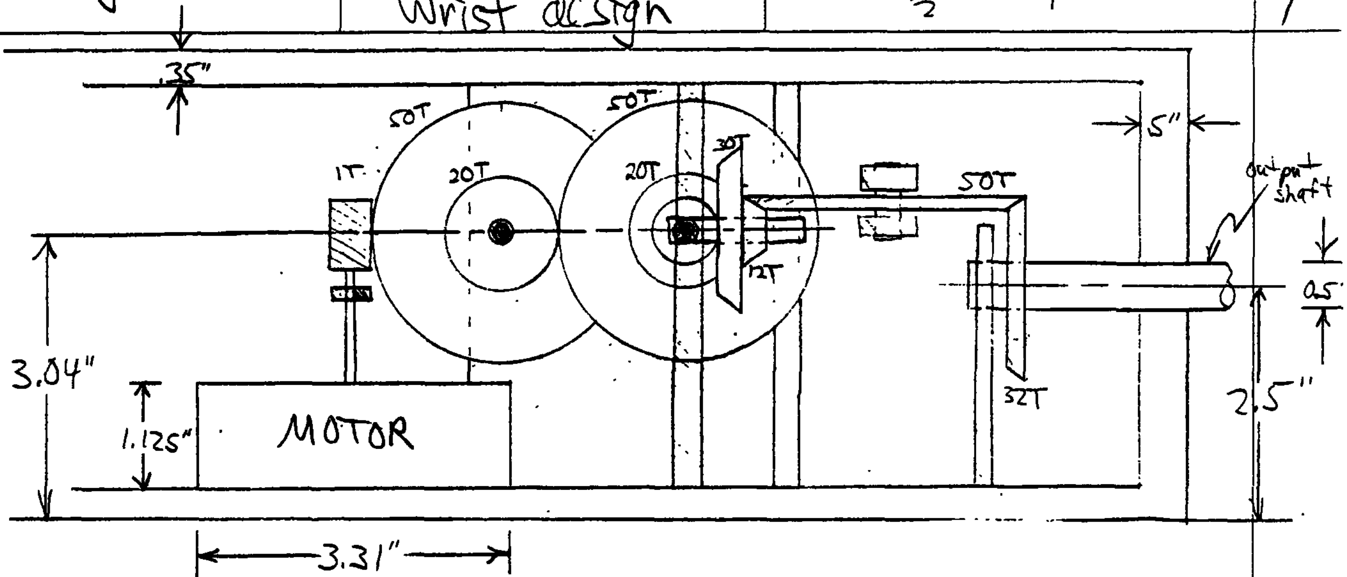
Weight of motor shaft with rotor arms



$$\pi\left(\frac{.375}{2}\right)^2 9 = .99402 \text{ in}^3$$

$$+ 2(3.6\times 1\times 1) \text{ in}^3$$

$$= 8.19402 \text{ in}^3 \left(\frac{.100 \text{ lb}}{\text{in}^3}\right)_{Al} = .819402 \text{ lb}$$



Gear weights: (approximate)

$$50 \text{ Tooth} \Rightarrow \pi(1.5'')^2 \cdot (.25'') \times 3 = 5.301 \text{ in}^3$$

$$30 \text{ Tooth} \Rightarrow \pi(.9'')^2 \cdot (.25'') \times 1 = .636 \text{ in}^3$$

$$20 \text{ Tooth} \Rightarrow \pi(.6'')^2 \cdot (.25'') \times 2 = .565 \text{ in}^3$$

$$12 \text{ Tooth} \Rightarrow \pi(.36'')^2 \cdot (.25'') \times 1 = .102 \text{ in}^3$$

$$32 \text{ Tooth} \Rightarrow \pi(.96'')^2 \cdot (.25'') \times 1 = .724 \text{ in}^3$$

$$1 \text{ Tooth Worm Gear} \Rightarrow \pi(.219)^2 \cdot (.75'') \times 1 = .113 \text{ in}^3$$

$$\text{Total Gear volume} = 7.441 \text{ in}^3$$

$$\text{Weight} \cong 7.441 \text{ in}^3 \times \left(.280 \tfrac{\text{lbs steel}}{\text{in}^3}\right) = \underline{2.08 \text{ lbs.}}$$

Support plates:

$$(2.5'')(.25'')(4.3'') \times 2 = 5.375 \text{ in}^3$$

$$(.75'')(.25'')(4.3'') \times 1 = .806 \text{ in}^3$$

$$(.625'')(.25'')(4.3'') \times 4 = .672 \text{ in}^3$$

$$\text{Total volume} = 6.853 \text{ in}^3$$

$$\text{Weight} = 6.853 \text{ in}^3 \times \left(.10 \tfrac{\text{lbs Aluminum}}{\text{in}^3}\right) = \underline{.685 \text{ lbs.}}$$

ORIGINAL PAGE IS OF POOR QUALITY

$$\text{Total weight} = 2.08 + .685 + 1.31 \text{ (motor weight)} + .13 \text{ (main shaft)} + .15 \text{ (gear shafts)} = 4.175$$

Motor specifications:

Aeroflex model TQ34W-12

Torque - 60 oz-in. continuous @ 1870.63 RPM

Power - 83 watts @ 1870.63 RPM

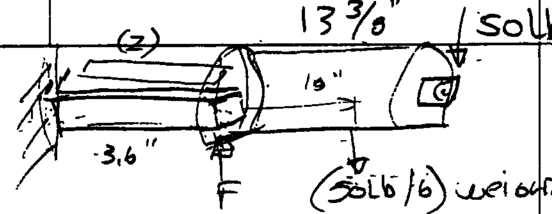
Max Torque - 80 oz.-in. @ 180 Watts

After 500:1 Gear down:

Continuous Output torque — <u>156.25 ft-lbs.</u>

Rotational speed of shaft — <u>3.74 RPM</u> (continuous)

WRIST DESIGN



$$V_{max} = \frac{\frac{1}{2}(267.23278)(3.6)^3}{3(10\times10^6)(.08333)} = .0025 \text{ IN}$$

OR $\underline{1/400"}$ ✓

$F(3.6) = 16.975(50) + 8.33(3.6)$

$\underline{F = 267.23278 \text{ lb}}$

$I = bh^3/2 = 1/12 \text{ in}^4$

ALUMINUM 3.6" x 1" x 1"

WEIGHT = $3.6 \text{ in}^3 \times .100 \frac{Lb}{in^3} = .36$ Lb

QUANTITY: 2 ∴ WEIGHT = .72 lb

BASE DESIGN

TOT. OUTER STRUCTURE WEIGHT = 208.5138 Lb

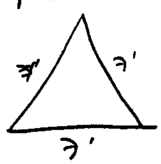
INNER STRUCTURES → (3) x TOP & BOTTOM (2) x 3.5' x12 I BEAM

$V = 6 \times 3.5 \times 12 \times 2.17 = 546.84 \text{ in}^3$

$W = 546.84 \times .1 = \underline{54.684 \text{ Lb.}}$

OUTER SKIN PLATES 1/16" THICK

TOP

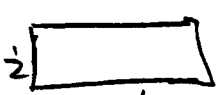


$V = 3.5' \times 12 \times 6.062178' \times 12 \times 1/16 =$

$= 190.9586 \text{ in}^3$

$W = 190.9586 \times .1 = \underline{19.09586 \text{ Lb}}$

3 SIDES



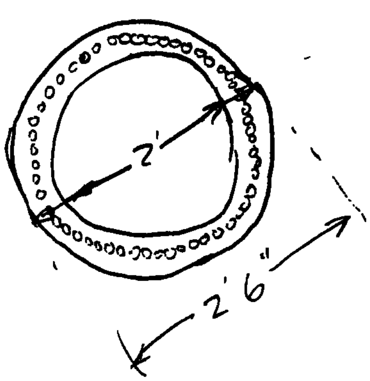
$V = (3) \times 2' \times 12 \times 7' \times 12 \times 1/16 = 378 \text{ in}^3$

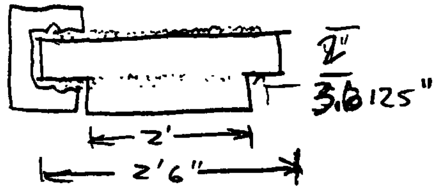
$W = 378 \times .1 = \underline{37.8 \text{ Lb}}$

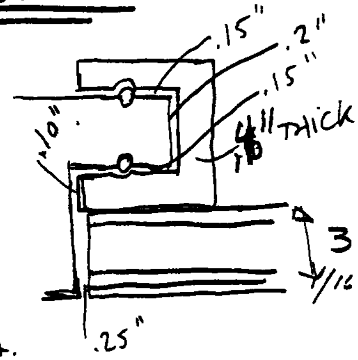
BOTTOM

$V = 190.9586 - \pi \times (12.24871)^2 \times 1/16 = 161.5001 \text{ in}$

$W = 161.5001 \times .1 = \underline{16.15001 \text{ Lb}}$





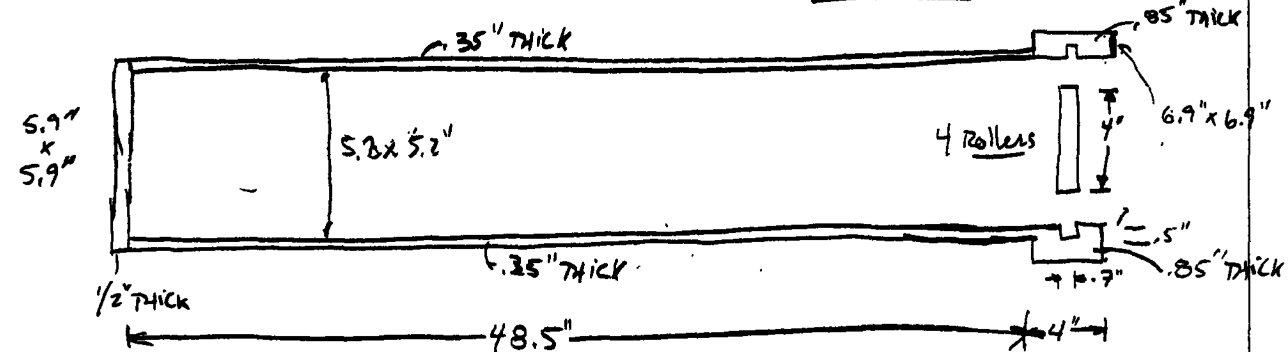


BALL BEARINGS .3" DIA.

SLEEVE: ALUMINUM

Volume = $.5'' \times 5.9'' \times 5.9'' + 48.5'' \times (5.9'' \times .35'' \times 2 + 5.2'' \times .35'' \times 2) + 4'' \times (6.9'' \times .85'' \times 2 + 5.2'' \times .85'' \times 2) - (.5'' \times .7'' \times 4'' \times 4) = 475.13 \text{ in}^3$

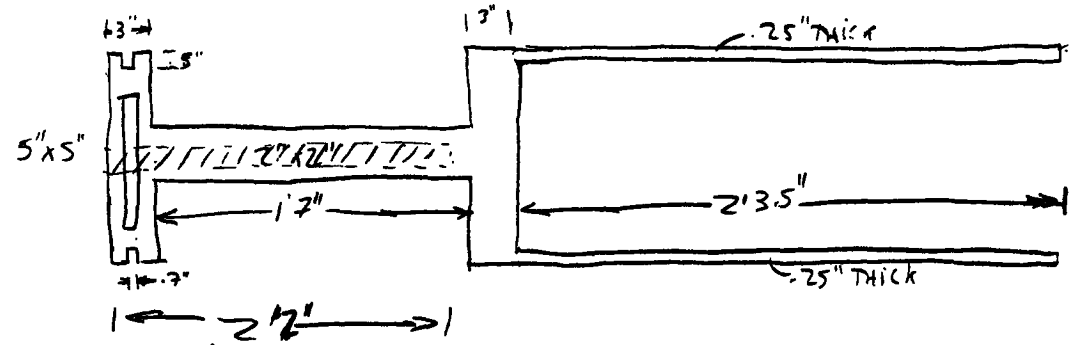
WEIGHT = $475.13 \text{ in}^3 \times .100 \text{ Lb/in}^3 = \underline{47.513 \text{ Lbs}}$



INSIDE ARM: ALUMINUM

$V = 2 \times (4'' \times 5'' \times 5'') + 2'' \times 2'' \times 19'' + 27.5'' \times (5'' \times .25'' \times 2 + 4.5'' \times .25'' \times 2) - 4 \times (.5'' \times .7'' \times 3.2'') - 26'' \times (.1875''^2 \times 3.14159) = 349.2734$

WEIGHT = $349.2734 \text{ in}^3 \times .100 \text{ Lb/in}^3 = \underline{34.92734 \text{ Lbs}}$



1/2" DIA - ASSUME BORE 3/8" DIA.

EXTENDING ACTUATOR — REFERENCING DUFF NORTON MECH. ACT.
UPRIGHT ROTATING BALL SCREW − W/ 4" CLOSED LENGTH
1/4 TON — EXTENDS 2'. (WITH EXTRA 2" FOR SURE HOLD)

REQD. TORQUE AT FULL LOAD = 13 in. Lbs.

MODEL # 4555 W/ ANTI-BACKLASH FEATURE.
WEIGHT W/ 6" RAISE = 2.33 lbs
EACH ADDITIONAL RAISE 1" = .1 Lbs (20 ADD. INCHES) = 2.0 Lbs

TOTAL WEIGHT = 2.33 + 2.0 = $\underline{4.33 \text{ Lbs.}}$

RAISE 1"/sec.

WORM GEAR RATIO 5:1 ∴ 20 TURNS OF WORM = 1" RAISE ∴ 1200 RPM REQ.

$Hp = \dfrac{13 \text{ Lb in} \times 1200 \text{ RPM}}{63{,}000} = .24752$ Hp. MOTOR REQD.

$\therefore$ WATTS = $\frac{.24752}{.001341022}$ = 184.57564 WATTS MOTOR @ 1200 RPM.

REQ'D TORQUE = 208 OZ. IN OR 1.0833 FT.lb

BRUSHLESS D.C. MOTOR.

SPECIFICATIONS: 185 WATTS AT 1200 RPM WITH A CONTINUOUS TORQUE OF 208 OZ-IN.

By approx from INLAND MOTOR SPEC. Book for A MOTOR OF NEARLY SAME SPECIFICATIONS. – THEY CLAIM TO Build A MOTOR TO OUR DIMENSIONS & SPECIFICATIONS. SO...

O.D. (in.) = 3.50" LENGTH (in.) = 1.00"
I.D. (in.) = 1.75" WEIGHT (Lb) = .75 Lb.

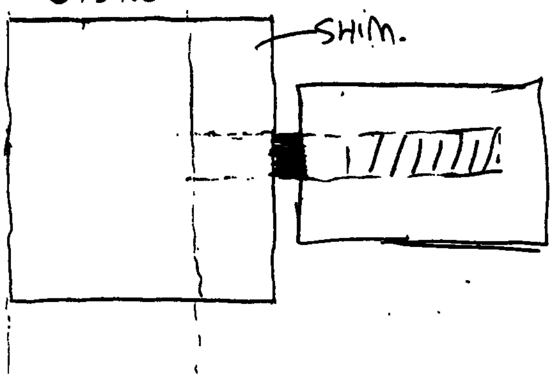
SHIM DESIGN TO FIT THE INSIDE OF ROTOR AND SHAFT OF WORM GEAR.. DIMENSIONS: STEEL

1" DEEP x 1.753" O.D x .373" I.D.

$$V = 1.4" \times \left[\left(\left(\frac{1.753"}{2}\right)^2 - \left(\frac{.373"}{2}\right)^2\right) \times \pi\right] = 3.22597\ in^3$$

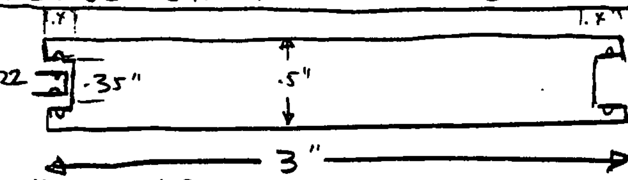
MOTOR CASING

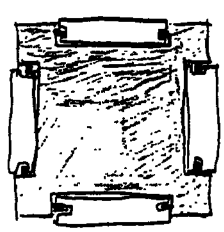
WT. = 3.22597 in^3 x .282 Lb/in^3 = .9097 Lbs



Rollers – : MATERIAL: STEEL ∴ – Solid

4 Rollers ON INSIDE SOLID ARM. (EXTENDER) ?





.075" DIA Ball Bearings.

$$\text{Volume (1)} = 3" \times \left(\left(\frac{.5"}{2}\right)^2 \times \pi\right) - \left(\left(\frac{.35}{2}\right)^2 \times \pi\right) \times .4" \times 2 - \frac{(.075)^2 \times \pi}{2} \times 2\pi \times 2 = .46273\ in^3$$

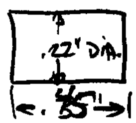
WEIGHT (1) = .46273 in^3 x .282 Lb/in^3 = .13049 Lb

QUANTITY = (4) ∴ TOTAL Roller WEIGHT = 4x .13049 Lb

(4) WEIGHT TOTAL = **.52196 Lb**

Pins & Ball Bearings

2 Pins Per Roller, 4 Rollers ∴ 8 Pins MADE OF STEEL
.22" DIA, .35" LONG - ATTACHES TO SOLID PART OF EXTENDER ARM.



$$\text{Volume (1)} = \left(\tfrac{.22}{2}\right)^2 \times \pi \times .35" = .01711\ in^3$$

$$\text{QUANTITY (8)} = 8 \times .01711\ in^3 = .13685\ in^3$$

$$\text{TOTAL PIN WEIGHT} = .13685\ in^3 \times .282\ Lb/in^3$$

(8) TOTAL WEIGHT = **.03859 Lb**

Ball Bearings

$\frac{(.35-.22)"}{2} + .22" = .285"$ - centerline of axis of Ball Bearings

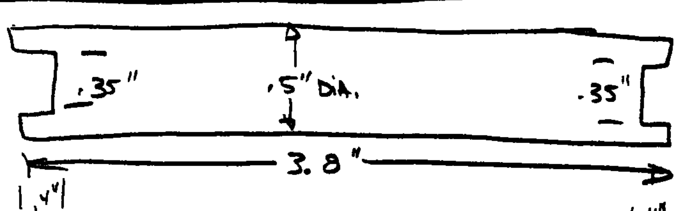
circumference = $.285" \times \pi = .89535$ in   EA. Ball Bearing
HAS .075" DIA. ∴ $.89535 in / .075 in = 11.938$ Ball Bearings
would fit leaving us to round to just 11 Ball Bearings
Per Pin, 8 Pins = 88 Ball Bearing (STEEL).

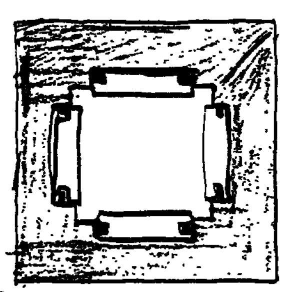
$$\text{Volume} = \tfrac{4}{3}\pi\left(\tfrac{.075"}{2}\right)^2 = .00589\ in^3 \times 88 = .51836\ in^3$$

$$\text{WEIGHT} = .518363\ in^3 \times .282\ Lb/in^3 = .146178\ Lbs$$

4 Rollers on outside sleeve cover.

MAT. STEEL - solid
.075" DIA. Ball Bearings





$$\text{Volume (1)} = 3.8" \times \left(\tfrac{.5"}{2}\right)^2 \times \pi - \left(\tfrac{.35"}{2}\right)^2 \times \pi \times .4" \times 2 - \left(\tfrac{.05"}{2}\right)^2 \times \pi \times 2\pi \times 2 = .61981\ in^3$$

$$\text{WEIGHT (1)} = .61981\ in^3 \times .282\ Lb/in^3 = .17479\ Lbs$$

QUANTITY (4) ∴ TOTAL weight = 4(.17479 Lb) = **.69915 Lbs**

Pins & Ball Bearings

2 PINS / ROLLER, 4 ROLLERS ∴ 8 PINS — STEEL
.22" DIA. .45" LONG - ATTATCHES TO SOLID PART OF SLEEVE.

$$\text{Volume}(1) = \left(\frac{.22''}{2}\right)^2 \times \pi \times .45'' = .0171\,in^3 \times 8 = .13685\,in^3$$

$$\text{TOTAL PIN WEIGHT} = .13685\,in^3 \times .282\,Lb/in^3 = \underline{\underline{.03859\,Lb}}$$

<u>BALL BEARINGS</u>

$$\left(\frac{.35'' - .22''}{2}\right) + .22'' = .285'' - \text{centerline of axis of Ball bearings}$$

CIRCUMFERENCE = $.285'' * \pi = .89535\,in$. EACH BALL BEARING HAS A .075" DIA. ∴ $.89535\,in / .075'' = 11.938$ BALL BEARINGS.

SO WE ROUND DOWN AGAIN TO 11 BALL BEARINGS / PIN

8 PINS ∴ 88 BALL BEARINGS. (STEEL)

$$\text{Volume} = \tfrac{4}{3}\pi\left(\tfrac{.075}{2}''\right)^3 = .00589\,in^3 \times 88 = .51836\,in^3$$

$$\text{TOTAL WEIGHT} = .51836\,in^3 \times .282\,Lb/in^3 = \underline{\underline{.146178\,Lbs.}}$$

TOTAL WEIGHT FOR ENTIRE ARM DESIGN
(SLIDING ARM SEGMENT)

$$= \underline{\underline{95.02068\,Lbs}}$$

PLATE DESIGN

.4" Thick
Aluminum plate

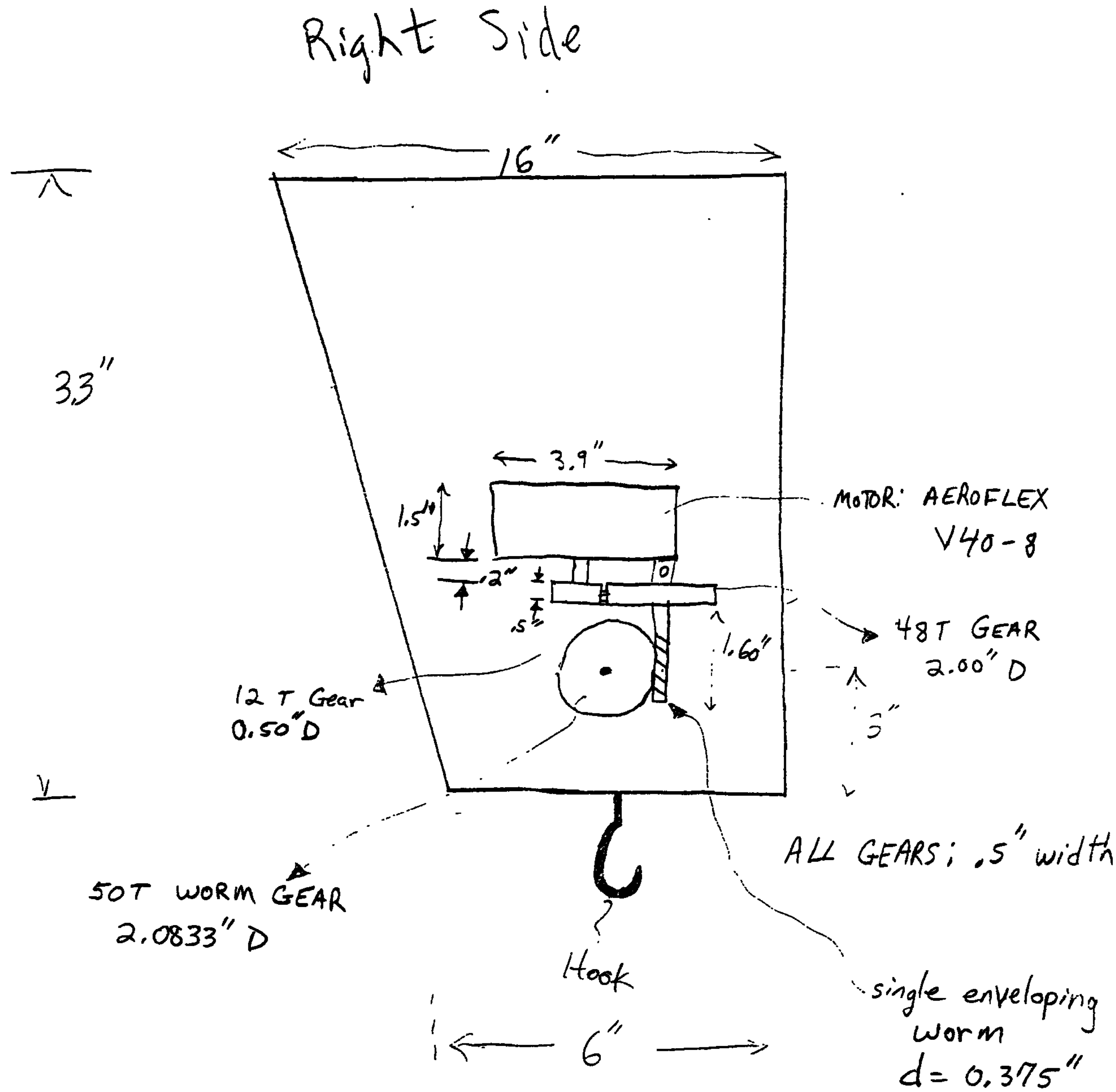


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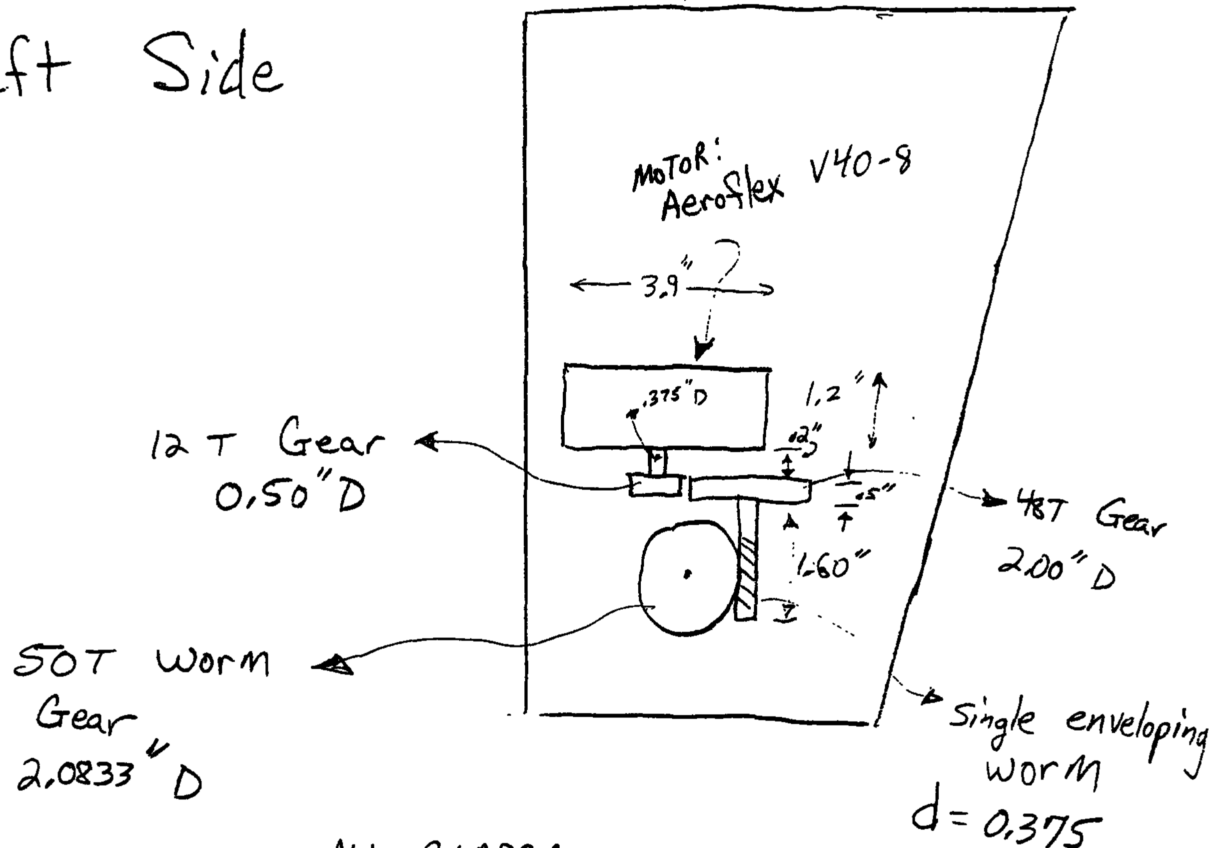
PLATE DESIGN (CONT'D)

Left Side



ALL GEARS:
0.50" Width

TOP VIEW

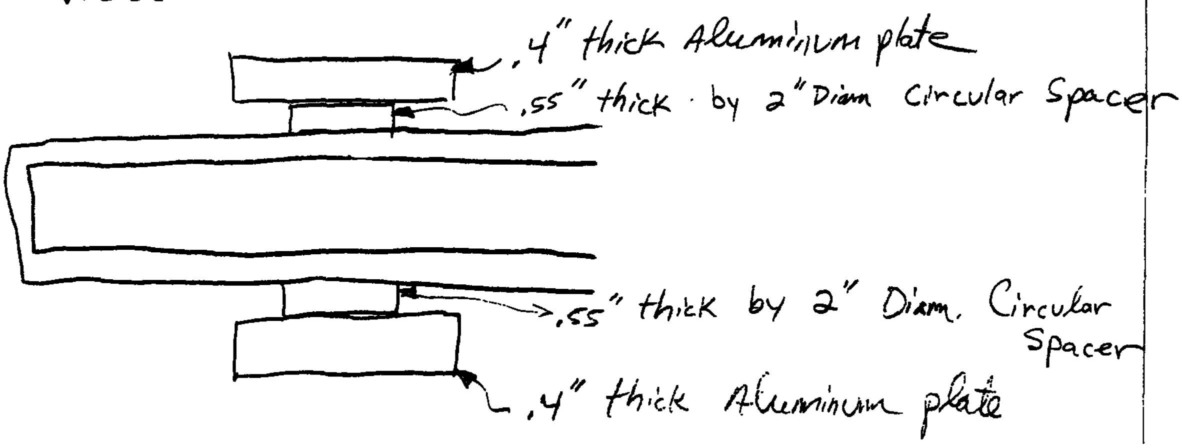
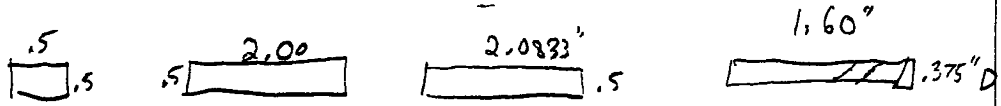


PLATE DESIGN (CONT'D)

MOTOR WEIGHT 2 AEROFLEX V40-8 MOTORS

55 oz ea. = 3.4375 lb ea = 6.875 lbs total motors

Gear train



$$\pi\left(\frac{.5}{2}\right)^2 .5 + \pi(1.00)^2 .5 + \pi\left(\frac{2.0833}{2}\right) .5 + \pi\left(\frac{.375}{2}\right)^2 1.60$$

$$\pi\,(.03125 \quad .5 \quad + \quad .54252 \quad 0.05625)$$

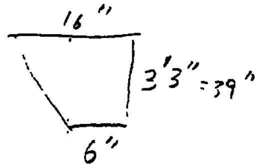
$$= \pi\,(5.63003) = 17.6873\ in^3$$

$$17.6873\,in^3 \left(\frac{.280\ lb}{in^3}\right)_{steel} = 4.952433\ lb$$

per gear train

total (both) gear trains = 9.905 lb

Weight of plates



$$= \left(.4" \times 6" \times 39" + \tfrac{1}{2}(.4" \times 10" \times 39")\right) 2$$

2 plates

$= 343.2\ in^3$ (both plates)

$$343.2\ (in^3) \cdot \frac{.100\ lb}{in^3} = \underline{34.32\ lbs}$$ (both plates)

Weight of spacers

$$2 \times (.55) \times \left(\frac{2}{1}\right)^2 \pi = 13.823\ in^3$$

$$13.823\ in^3 \left(\frac{.100\ lb}{in^3}\right) = \underline{1.3823\ lb}$$ (both spacers)

Weight of pins 2" long, .375" Diam

$$2\left(\pi\left(\frac{.375}{2}\right)^2 2\right) = 0.4417865\ in^3 \left(\frac{.280\ lb}{in^3}\right) = \underline{0.1237\ lb}$$

Weight of hook = $\underline{1.13\ lb}$

103125

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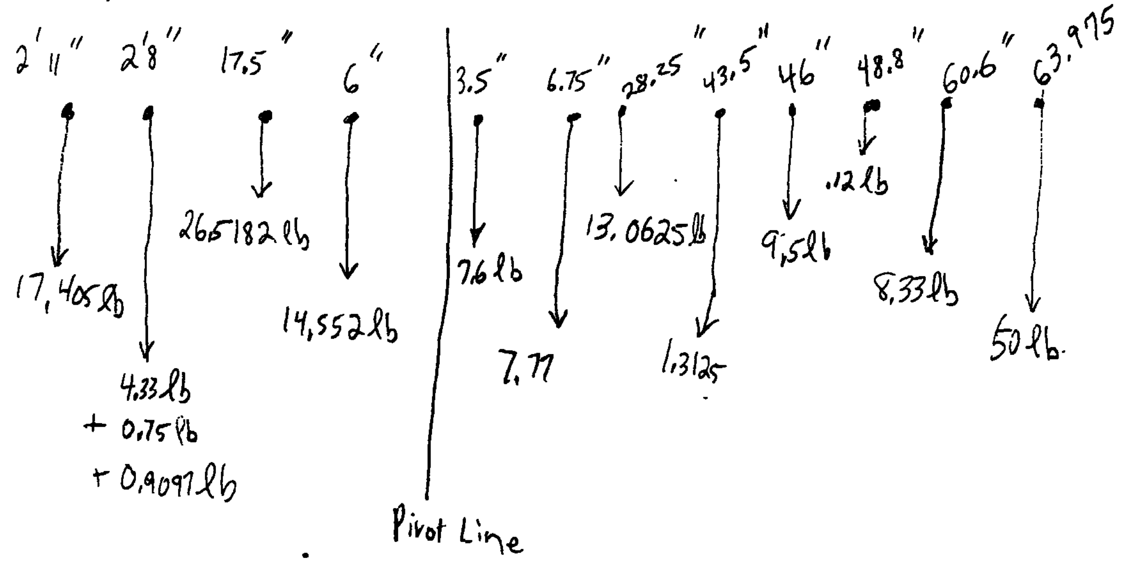
PLATE DESIGN (CONT'D)

Computing the torque required by the 2 motors to pivot the arm:



Sum of the torques ⇒

$35(17.405) + 32(5.9897) + 17.5(26.5182) + 14.552(6) + T =$

$(7.6)(3.5) + 7.77(6.75) + 13.0625(28.25) +$

$1.3125(43.5) + 9.5(46) + .12(48.8) + 8.33(60.6) +$

$50(63.975)$

$\Rightarrow T = 3299.335$ in-lb $(\div 2)$

$= 1649.6675$ in-lb/motor $= 137.47$ ft lb

geared at 200:1 ⇒ 131.97 oz-in

FROM AEROFLEX SPEC. BOOK

→ USE 2 V40-8 Motors

Continuous torque = 190 oz-in @ 572 RPM (80 WATTS)

Peak torque = 315 oz-in @ 1186 RPM (275 Watts)

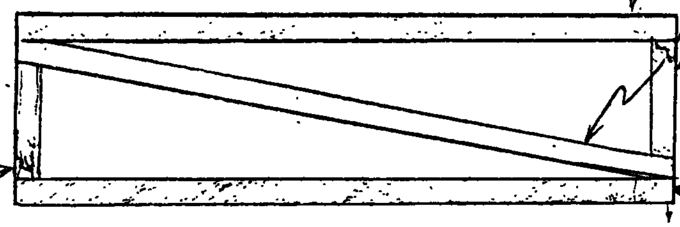
PLATE DESIGN (CONT'D)

MOTOR weight: 55 oz each = 3.4375 lb each

= 6.875 lbs total

Basic Frame Structure **Base Design** 1" = 2'

I-beams

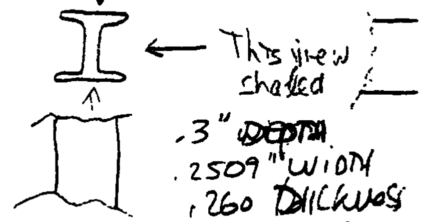


Angle irons (2½×2) 3/16" THICK on each corner $A = .81\ in^2$

$\frac{1}{16}$" sheet aluminum

3"×2⅜" I-Beams

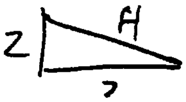
into view plain



This view shaded

.3" DEPTH
.2509" WIDTH
.260 THICKNESS
.349 - web thickness

All three sides will have this structure. $= 2.17\ in^2$

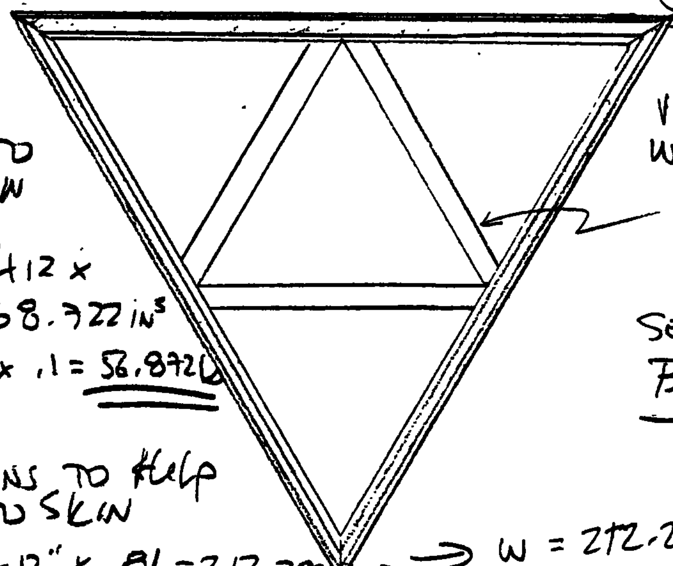


$H = \sqrt{53} = 7.2801'$

(3) 7' LONG I BEAMS FOR LOWER & (3) FOR UPPER TRIANGLE.

$V = 6 \times 7 \times 12 \times 2.17 = 1093.680$

$W = 1093.680 \times .1 = \underline{109.368\ Lb}$



3×2⅜ I-beams, as above

(3) ANGLED I BEAMS TO SUPPORT SKIN

$V = (3) \times 7.2801' \times 12 \times 2.17 = 568.722\ in^3$

$W = 568.722 \times .1 = \underline{56.8722\ lb}$

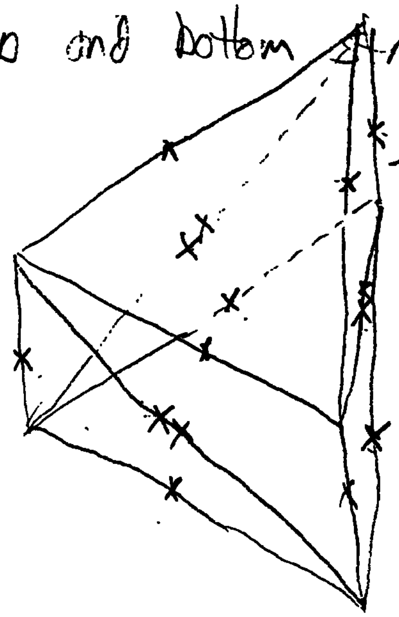
SEE ALSO PG. 6 FOR BASE DESIGN CALCULATIONS

(3) ANGLE IRONS TO HELP TO ATTACH TO SKIN

$V = (3) \times 7.2801' \times 12" \times .81 = 212.288\ in^3 \rightarrow W = 212.288 \times .1 = \underline{21.2288\ lb}$

Top and bottom structure are the same.

Skin for base on back.



OUTER STRUCTURE

3 VERTICAL 1'6" LONG TRIANGULAR 3"×3"×3" SIDE BASE ALUMINUM

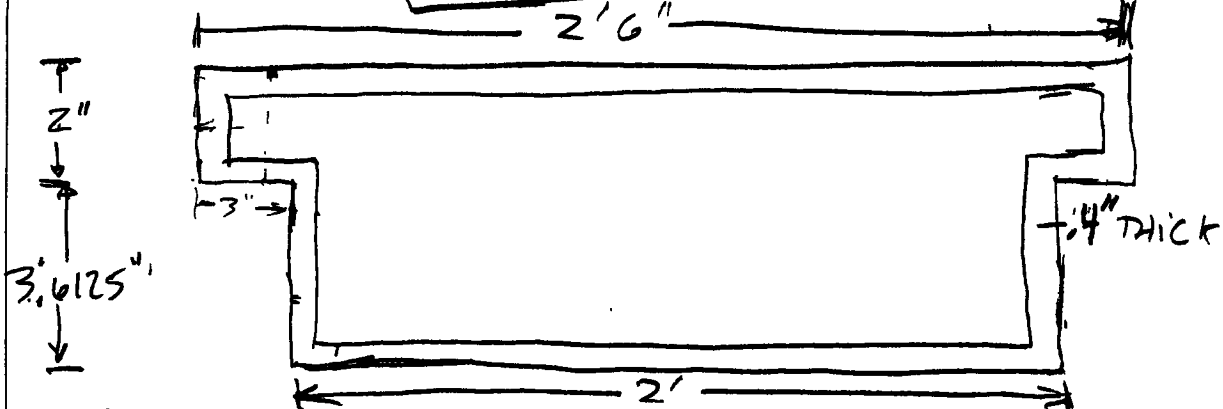
$V = 18" \times 1.5" \times 2.59808"$

$V = 70.148\ in^3$

$WEIGHT = 70.148 \times .100 = 7.0148\ Lb \times 3$

$= \underline{21.0442\ Lb}$

BASE DESIGN

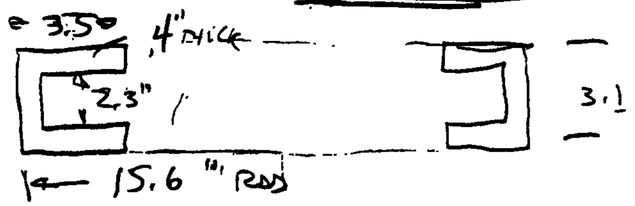


DRUM

$$Volume = \pi(12^2) \times .4 + \pi(15^2).4 + 1.2 \times \pi(15^2 - 14.6^2) + .4 \times \pi \times (15^2 - 11.6^2) + \pi \times (12^2 - 11.6^2) \times 3.2125 = 717.257 \ in^3$$

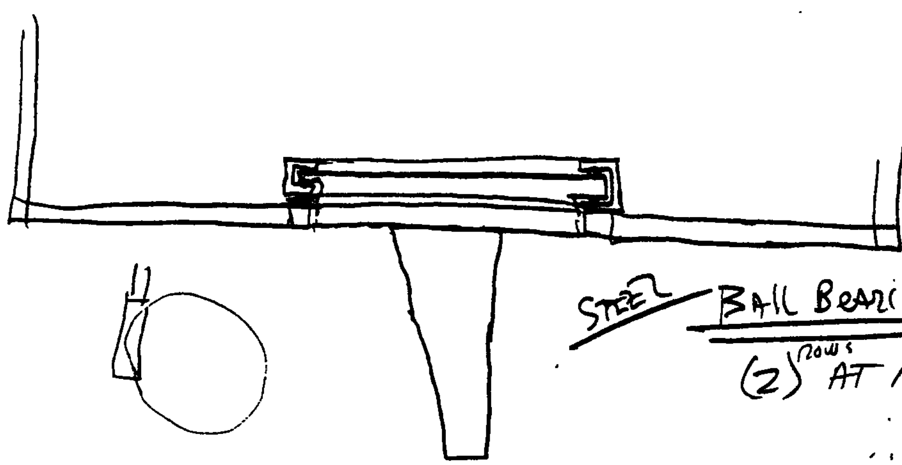
$$WEIGHT = 717.257 \times .1 = \underline{71.7257 \ Lbs}$$

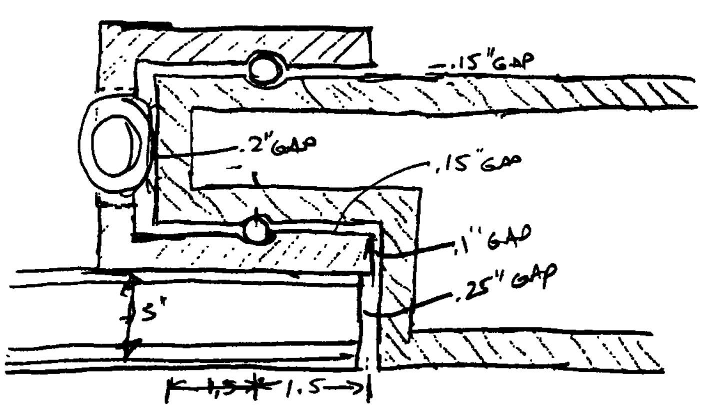
RING GUIDE



$$Volume = \pi(15.6^2 - 12.40^2) \times .4 \times 2 + \pi(15.6^2 - 15.20^2) \times 2.3 = 332.682096 \ in^3$$

$$weight = 332.6821 \times .1 = \underline{33.26821 \ Lbs}$$





STEEL BALL BEARINGS .3" DIA. EACH

(2) ROWS AT A RING OF RADIUS 13.5"

$$\therefore CIRCUM. = \pi 2R = \pi(2)(13.5) = 84.823"$$

$$84.823 / .3 = 282.74$$

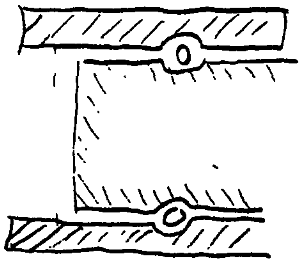
THEREFORE USE 280 BALL BEARINGS.

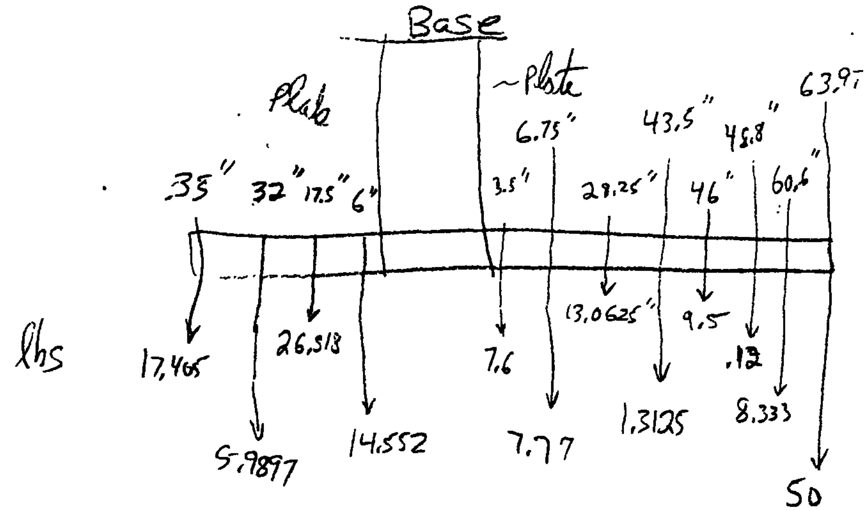
(2) ROWS $\therefore$ 560 TOTAL

$$V = \frac{4}{3}\pi(.15)^3 = .01414 \ in^3$$

$$WEIGHT = .01414 \times .282 \times 560 = \underline{2.2325 \ Lb}$$

BASE DESIGN

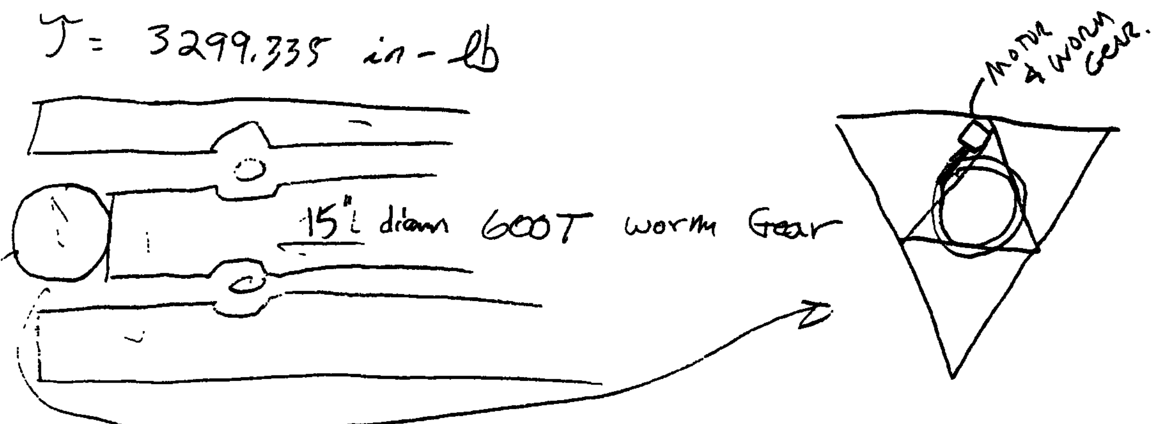




Sum of torques ⇒

$$35(17.405) + 32(5.9897) + 17.5(26.5182) + 14.552(6) + T =$$
$$7.6(3.5) + 7.77(6.75) + 13.0625(28.25) + 1.3125(43.5)$$
$$+ 9.5(46) + .12(48.8) + 8.33(60.6) + 50(63.975)$$

$T = 3299.335$ in-lb



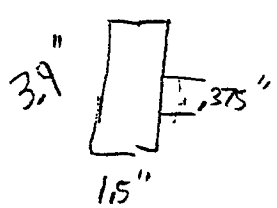
double-enveloping worm

- driven by Aeroflex Labs V40-8

Peak torque = 315 oz-in (275 watts)

Continuous torque = 190 oz-in (80 watts)

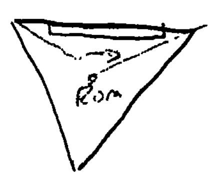
55 oz = 3.4375 lbs



ACCESS -
10 W Alloys

TOOL RACK

5' × 4" ATTACHED TO SIDE OF BASE



WEIGHT LIMIT
20 LBS

ARM

12 WEIGHT COST & POWER CONSUMP

ARM

Sleeve 47.513 lb
INSIDE ARM 39.92734 lb
A ACTUATOR 4.33 Lb
MOTOR & SHIM 1.6597 Lb
Rollers & Ball BEARINGS 3.25035 lb.
ARM TOTAL 96.68 Lb

WRIST

MOTOR 1 = 1.875 Lb
GEAR 1 = 1.797 Lb
WRIST = 20.29723
SHAFT 1 = .819402
GEAR 2 = 2.915
MOTOR 2 = 1.31
SHAFT 2 = .13

WRIST TOTAL 29.1436 Lb

ARM TOTAL WT
125.823

POWER CONSUMPTION

ARM — CONT. 184.57564 WATT
WRIST 1 — PEAK 230 W
CONT. 50
WRIST 2 - PEAK 180 W
CONT. 83 W

ASSUMED PEAK 550

PEAK 960 W
CONT. 317.57564 W

MAIN PAPER

TOPIC. — Power ~~CONSUMPTION~~ Production --
Fuel cell

1.5 KW

Overview

OV
D.C.
S.?

The fuel cell in the robotic arm must be capable of generating a clean, DC signal & peaks up to 3 Kw. One promising option is the hydrogen/oxygen conversion cell. This system, similar to what is currently used on the space shuttle, combines hydrogen and oxygen to form water and produce electricity.

Another promising option is the solar-rechargeable batteries. Essentially, this is an on-board battery pack which can be recharged by a bank of solar panels. This has the advantage of being easily refillable, but the disadvantage that a ~~large~~ bank of solar panels ~~be~~ must be built

~~BASE~~ $\boxed{\text{BASE}}$

#12 Weight - Cost / ~~Power~~ Consumption

BASE see CALCULATION IN Appendix

THE BASE FRAMEWORK WEIGHS
263.197 Lb OF ALUMINUM

THE 1/16" SKIN COVERING FRAMEWORK WEIGHS
73.04587

THE DRUM & RING GUIDE & BALL BEARINGS WEIGH
107.22641

MOTOR & GEARS WEIGHT
13.4375

TOOL RACK (MAX.)
15 Lbs

BASE TOTAL: 456.9063 Lb.

PLATES

PLATES weight	34.32 Lb
SPACERS weigh	1.3823
GEAR TRAINS	9.905
MOTOR	6.875
PINS	.1237 Lb
HOOK	1.13 Lb.
TOTAL	53.736 lb

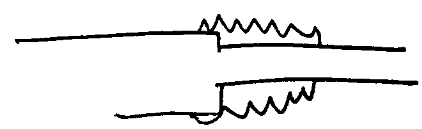
BASE TOTAL WT.
526.6423 Lb

~~BASE~~ Power consumption

	PEAK	CONT.
BASE	275 W	80 W
PLATES	550 W	160 W

PEAK	CONT.
825 W	240 W

ARM



#9 Range of Motion - Work Envelope

THE SCRAM WAS DESIGNED FOR THE BOTTOM OF SKITTER, WHICH HAS A VERY GOOD RANGE OF MOTION ITSELF. THEREFORE SCRAM'S PURPOSE WAS MORE FOCUSED ON STABILITY WITHIN ITS RANGE OF MOTION.

THE SCRAM UNIT WILL OPERATE ONLY BETWEEN 2 OF SKITTER'S LEGS, THEREFORE IT RANGE OF MOTION AT THE ROTATING DRUM IN THE BASE IS 120°. THE PIVOT POINT FOR THE TELESCOPING ARM IS LOCATED 3' BELOW BOTTOM OF DRUM. THE RANGE OF MOTION FOR THIS PIVOT IS 150°, FROM PERPENDICULAR DOWN TOWARDS THE GROUND TO 30° FROM PERPENDICULAR UP TOWARDS THE DRUM.

THE TELESCOPING ARM CAN REMAIN RETRACTED (AS SEEN IN DRAWING) OR IT CAN EXTEND THE INNER ARM 2' BEYOND ~~ITS~~ 4" RETRACTED LENGTH. THE TELESCOPING INNER SEGMENT CAN BE STOPPED AT ANY POINT DURING ITS TRANSLATION AND WILL BE HELD STEADILY BY the self-locking action of the WORM GEAR.

THE WRIST HAS 2 DEGREES OF FREEDOM. ONE ROTATES AT THE POINT WHERE THE WRIST MEETS THE END OF THE TELESCOPING ARM; THIS JOINT HAS A 360° RANGE OF MOTION. THE OTHER DOF (degree of freedom) TURNS THE END EFFECTOR THROUGH A 180° OF MOTION, ~~FROM FACING~~ DOWN, 90° ~~PERPENDICULAR TO~~ ARM ~~TO FACING~~ UP ~~90° PERPENDICULAR TO ARM~~.

~~[illegible]~~

from 90° to either side of the center line through the sliding arm.

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